A QUANTITATIVE ASSESSMENT OF A LEED CERTIFIED CAMPUS BUILDING

A Thesis

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ABSTRACT

In today's society, sustainability is a key word in the building design and construction industry. But how does one measure the sustainability of a building? The LEED program offers a rating system based on certain criteria, but how would one compare alternate buildings and certain design decisions? To answer these questions several tools and programs have been developed to evaluate the environmental impacts of the material and assemblies from the time they are extracted as minerals, manufactured, constructed, replaced and demolished with the building. This process is known as a life cycle analysis. This study intends to develop a method to analyze a LEED Certified building using commercially available life cycle analysis software. Another aspect of this study was to research how the building selected for the analysis completed the requirements for LEED certification.

The building used for this study was the LEED Certified Ohio 4-H Center on the campus of the Ohio State University. The program used for the analysis was the Athena: Impact Estimator which using life cycle analysis of building assemblies to determine the energy and resource use at each stage of the life cycle. The results of this study found that this method of analysis can be used to predict the life cycle consumption of a pre-constructed building based on the building plans and energy consumption over one year. It was also found that this tool would be better utilized as a design tool early in the conceptual or pre-planning stages for comparing similar designs due to the restrictions on

the inputs that are available for current versions of the program. This study also summarized the design and construction details implemented in order for the 4-H Center to be LEED Certified.

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Chapter 1 - Introduction

1.1 - Overview

Each year buildings consume vast quantities of energy and raw materials while releasing greenhouse gases into the atmosphere. In order to curb this consumption rate, research and development of more energy and resource efficient structures is taking place all over the world. While some standards for buildings have been developed in the United States and other countries, comparisons of structures using the current domestic standards is not possible. This is because most green rating systems are prescriptive and are simply a rating given for meeting a set of predetermined criteria. Even with these current rating systems it becomes difficult to quantify the sustainability of new buildings and other construction projects. Even more evident is the lack of guidance and development in the area of sustainable practices by structural engineers who play a vital role in the rapidly changing world today.

1.2 – Background and Research Impetus

Annually, buildings consume vast quantities of raw materials and energy which results in a significant negative impact on the environment. Worldwide buildings consume 40% (3 billion tons) of available raw materials for construction and operation (San-Jose, 2007). Because of this, it is starting to become commonplace for architects and engineers to attempt to reduce the consumption and design structures that will enable the environment and resources to be sustained for future generations. The interest in the widespread development of sustainable structures has only been adopted recently, despite the call for more sustainable development in the Brundtland Report titled Our Common Future (1987), where sustainability was defined as "…development that meets the needs of the present without compromising the ability of future generations to meet their own needs". This idea has since been adopted by the engineering and construction industry as a standard. The objective is to design and construct a more efficient product that reduces energy consumption. This reduction in energy consumption traces the energy used to create, operate and finally destroy the product. Often a slightly higher initial cost for a more sustainable alternative is typically offset by the energy savings over the life of the product (Cole, 1996).

All over the world, standards to measure sustainability have been put in place. In the United States these initiatives have manifested themselves in the LEED building certification program (Leadership in Environmental and Engineering Design), Energy Star rating system, and Green Globes certification which is similar to the LEED Program. The LEED Program Version 2.2 (2005) consists of 69 possible points that are possible for the designer to attain through various methods. Such methods include the use of recycled and local materials (USGBC, 2005). The drawback of each program is that points are obtained by meeting certain criteria. The point accumulations then determine the rating. These rating systems, based on a criterion approach, are easy to use and to understand but are not fully capable of modeling the complexities required for a comparison of different structural systems. For that an analysis of the material throughout its entire life cycle, known as Life Cycle Cost Analysis (LCA) should be implemented (VanGreem, 2006).

More recently, research and standards using life cycle cost analysis have been used more frequently. European countries such as Finland, the United Kingdom, France, Spain, Sweden, and the Netherlands are already using life cycle analysis to measure the sustainability of structures by developing their own analysis and rating programs (San-Jose, 2007). Similar research is currently being developed in North America. Canadian researchers, as part of the larger Athena project (Athena Institute, 2008), studied the Life Cycle energy use of a generic three story building with and without underground parking for wood, steel, and concrete structures. The United States is currently behind the European Union and other parts of the world in sustainability research. However, new research and sustainability initiatives are currently being implemented across the United States.

The Ohio State University Medical Center is entering a new phase of expansion and growth and has decided to transition to facilities that practice innovative research into sustainable design. This will be accomplished by remodeling some building while demolishing and rebuilding others. This project is titled the Value Assessment of Sustainable Technology (VAST). The two objectives of this initiative are to measure and to validate the actual financial and human benefits of sustainable design and to develop empirical evidence of the value of sustainable design. This project is a cooperative effort among the OSU Medical Center, OSU College of Engineering, OSU Center for Resilience, and the US Environmental Protection Agency. This research will explore one way to measure the sustainability of a campus building through commercially available life cycle analysis software.

1.3 - Objective and Scope

This project aims to build on the existing research on the comparison of the reduction in materials and energy consumption of a LEED certified building on the Ohio State University campus. The analysis will use the proposed university building and will compare the energy and cost associated with the construction, operation and maintenance and the demolition of the building over its expected lifetime using a life cycle or "cradle-to-grave" analysis. In addition, a variety factors involved in sustainable design as it applies to the structural engineering practice are discussed. Furthermore a case study of a newly LEED Certified campus building about the specific design and construction details that were included for its LEED certification is included as well.

1.4 - Organization

The sustainability research presented includes a literature review, application to structural engineering practice, and a case study model of the Ohio 4-H Center using life cycle analysis. Chapter 2 contains the literature review which discusses the previous research done on this topic and discusses the importance of this previous experience to this project. Chapter 3 presents a discussion on the incorporation and factors of sustainability into structural design and engineering. The 4th chapter presents a case study of the Ohio 4-H Center and each LEED criteria attempted for this building is presented. The main research work is presented in Chapter 5 including the application of the methodology for modeling the 4-H Center using the appropriate environmental software. The discussions and conclusion for this model and future recommendations are included in Chapter 6.

Chapter 2 – Previous Research on Sustainability

2.1 – Introduction

While sustainability is a relative term for the design processionals, this can be seen from the recent enormous interest by not only the academic community but from governments and corporations to build sustainable structures. Most of the research on the quantification, measurement and the design aspects of sustainable construction has been performed over the last 10 to 15 years. This chapter presents some of the literature reviewed for this project that developed ideas pertaining to sustainable structural design and using life cycle analysis to help quantify the sustainability of structures.

2.2 – Sustainable Structural Design

In this section, several articles are reviewed that discuss ways that sustainable design may be incorporated into structural engineering practice.

2.2.1 – Allen (2007)

Allen (2007) discusses some of the barriers and incentives to some firms for incorporating sustainable design practices into their projects. He notes that some firms see this as too difficult or expensive to incorporate and equate it with the green hippie movements of the 60's and 70's while other, more forward looking firms are embracing the concepts and practices as a new marketing strategy and recruitment tool for bringing new clients and engineers to their firms. However, he notes that this integration can only be successful if the structural engineer is able to integrate with the other building system design early in the conceptual design process. He further says that while some metrics and rating systems such as LEED (Leadership in Energy and Environmental Design) (USGBC, 2005) apply to the sustainability of the total project and not to the material themselves, or other metrics, based on a life cycle assessment; apply to the projects as well as the materials that go into those projects. One of the metrics that do consider the whole assembly is the Athena Institute model. Allen offers two strategies for the structural engineer to incorporate into their designs to enhance sustainability of the structure. The first is durability, which is the design of a structure for minimal maintenance and enhancing its lifetime. The second is to design for adaptability and deconstruction. He states that designing for adaptability means designing a structure so that it can easily undergo changes in its purpose or that it can easily be disassembled and members can be reused on other sites.

2.2.2 – Field (2007)

R. Field of the Structural Engineering Institute Sustainability Committee discussed some of the inherit difficulties in his article where he begins with a question "…which [is] the most sustainable [material]: wood, steel or concrete?" This is a practical question and a meaningful one to structural engineers involved in the selection of material. There is no material property that allows one to measure its sustainability. Field (2007) says that the way to quantify sustainable aspects of structural materials is through a life cycle assessment and "choosing the right material for the right role is really at the heart of sustainability." He also says that one of the problems with the life cycle assessment is the large volume of data for the effects of each product through its lifetime and that the different impacts of the material are so varied that they are difficult to compare.

2.2.3 – Webster (2007)

Webster (2007) discusses the importance of "designing structures for adaptability and deconstruction." He found less than half of demolitions were a result of the "building's physical condition." Most were demolished because they were unable to be adapted to the changing needs of the community. This highlights the importance of designing structures that can be changed and that can adapt to the needs of the future. In this case some components may be over designed if there is a desire to alter the structure in some way that may require more strength such as reconfiguring the partitions or rooms on a floor.

He also discusses deconstruction, which he defines as a demolition method where a structure is carefully disassembled so that much of the structure can be salvaged as possible with the ultimate goal of using most of the components "as is". He states the "the goal here is not merely to recycle but to reuse." Recycling consumes energy and in contrast to reuse, is not as sustainable. However a structure must be originally detailed in such a way that makes deconstruction possible, as decisions for these specifications would be required early in the planning stage.

2.2.4 – Vesilind et al. (2007)

In their article, "Kermit's lament: it's Not Easy Being Green", the three authors discuss the topic of sustainable design as it applies on a professional and moral level. They present the "precautionary principle". This principle state that if a problem is "sufficiently severe and the consequences sufficiently serious", then proof is not needed before action is taken to remedy the situation. They also mention that it is this principle that leads to the determination of the definition of sustainability by the Brundtland Commission of 1987, that sustainability is defined as “development that meets the needs of the present without compromising the ability of future generations to meet their own needs.” One of the goals of sustainability is to “prevent the collapse of the global ecosystem’ and to aid “developing nations manage their resources.” They also found that recycling more than 25% of materials exponentially increases the energy, environmental and monetary commitment involved in the recycling process. Also, in discussing the reasons that individual engineers and companies have turned to “green” design, they found that often it was more economical and more efficient for the company to adopt these practices and that it saved them money in the long run. On the other hand, individual engineers surveyed often cited different reasons such as the responsibility to future generations or that from an ethical standpoint it is the right thing to do. Visilind et al. (2007) also point to Aristotle and his theory of “*eudaimonia”* which is the most basic desire which is happiness. He claims that it is this desire to be happy that drives everything that people do.

2.2.5 – Kren (2007)

At the 2007 Structures Congress, Kren proposed that sustainability is about working within the limits of the available natural resources. For example, water is a resource and altering the flow of streams or even expelling heated cooling water can damage ecosystems and in many areas of the world, the supply of clean water can outweigh the demand. In other cases, mining can damage environments and destroy other industries in the area and the atmosphere is limited in its ability to absorb green house gases. He also states that in efforts to minimize weights and costs, structural engineers have been reducing the demands for certain resources and the creation of certain emissions related to the creation of structural materials. He proposes considering the effects on the environment during the design process, just as an engineer would consider the building codes, safety factors and the effect on the current population.

2.3 – Life Cycle Analysis

In this section, several articles are reviewed that discuss the quantification of the sustainable characteristic of structures through life cycle analysis as well as the use of software and programs that are designed to rate the these characteristics.

2.3.1 – Cole and Kernan (1996)

Cole and Kernan (1996) developed a life cycle analysis model that compared the energy use of three generic office buildings, constructed with wood, steel and concrete. They analyzed the models on the basis of the initial embodied energy, the recurring embodied energy, the operation energy, and the demolition energy and compared the results for each. The initial energy is the energy associated with the materials and construction of the building itself. The recurring energy is from the renovation and maintenance of the building and the operational energy from running the office from day to day. The demolition energy is the energy associated with the deconstruction and demolition of the building. They found that 70-80% of the life cycle energy use came from the operating energy while the initial embodied energy only constituted about 10% of the life cycle energy use. They also found that the most sustainable building material varied depending on the lifespan, option of underground parking and other factors.

2.3.2 – Centre for Design at RMIT (2001)

The Royal Melbourne Institute of Technology (RMIT) issued a background report in 2001 that grouped all of the sustainability assessment tools on the basis of function and analysis. This report classified the LEED system as a "building rating scheme" which "concentrates on operational measures of building performance." The report also classifies the Athena Impact Estimator as "Detailed LCA Modeling Tool" which incorporates material and process databases. They also created a table with all of the available tools and a listing of each of their capabilities for comparison. This table can be found in Appendix A.

2.3.3 – Mithraratne and Vale (2004)

Mithraratne and Vale (2004) developed a model to create a life cost analysis of standard New Zealand houses as a design tool that would give designers a method to compare alternative designs as well as the environmental impact that certain design decisions would have over the lifetime of the structure. This method was meant to build on the "broad brush" or criteria approach of the Green Home Scheme that was created by the Building Research Association of New Zealand. After developing this model, the researchers used the model to compare the life cycle costs of three similar basic home constructions, one of a typical wood frame house, the second replaced the floor with a concrete slab and the third was the same as the second with twice the insulation materials. The results of their model indicated that the insulation of the floor in the second model and the floor and walls in the third greatly reduced the operating energy over the lifetime of the structure. They also concluded that operating energy is a quick way to predict the overall impact of a structure.

2.3.4 – San-Jose et al. (2007)

The authors define industrial sustainability as being supported by the three pillars of environment, economy, and society. Before this article, most industrial sustainability had to do with the processes inside of the building but the authors intend to extend it to the building envelope itself. This article presents a life cycle assessment through an "analytic hierarchy process (AHP)" which divides predetermined categories into smaller categories until the impact for certain environmental indicators can be found.

2.4 – Conclusions

After reviewing the articles on sustainable design and life cycle analysis, it was found that the application of sustainability to structural design was rather limited and difficult. In order for environmental design to impact the structural aspects of a project, the decision to do so by the client must occur early in the design process. Even then, the embodied energy of the structure is much less than the operating energy and the embodied energy for the structure is much less than the rest of the building envelope. Thus the structural envelope has little impact on the sustainability of the structure as a whole. However, a certain amount of foresight can increase the adaptability of a structure which will make it not only more sustainable, but more profitable favor the client as the building can have a longer lifespan.

The review of previous research on life cycle analysis and green metric software has revealed the inadequacies of the LEED rating scheme and the need for a North American life cycle analysis tool. Currently, that tool is the Athena: Impact Estimator which creates a bill of materials and the life cycle effects through the creation of building assemblies. This tool can be used to model an entire building structure and outputs the results by life cycle stage and can also compare different building models.

Chapter 3 - Sustainable Structural Design

3.1 – Definition of Sustainability

Sustainability, or "green" is the new buzzword in the design and production industries, but what does it mean to be "green"? Sustainability is defined as servicing the needs of the present without compromising the opportunities for the future. This is well known to the practitioners of sustainable design as defined in the Brundtland Report of 1987, *Our Common Future* (Brundtland, 1987). This definition suggests that the development of the present must be considerate to the availability of resources and materials so that future generations might be able to develop the world as they need and want. In order for this flow of resources and materials to endure for future generations, the rates at which the regeneration of these materials and resources must be equal to or larger than the rate of consumption, or be at steady state.

Since the 1980's however, the consumption of resources and energy has superseded the environments ability to replenish itself. This means that unless measures are taken to bring down consumption, sustainability or resources will be an impossibility and that future generations will run out of available resources (Vesilind, 2007). The fact that sustainable development and practices are necessary for the future of society and the environment is readily accepted. However, most people are silent on what should be done about it. Most people would agree that low energy products or renewable energy sources are the key to achieving sustainability, but what if it takes more energy and materials to produce these products?

Furthermore, it has been found through interviews of a variety of companies that they would be willing to implement sustainable practices into the manufacture of their product if it did not raise the price to produce the product. This means that the main opponent to sustainable design is the perceived "cost burden" associated with sustainable technologies (Ball, 2002). It has also been found that fines through government regulation are the primary motivator of most businesses to incorporate sustainable business practices (Ball, 2002). It is true that initially, costs are high for new technologies, however, these costs decline as they become industry standards. Furthermore, sustainable practices and products often reduce energy costs that can save money for the consumer. So it is the responsibility of companies, engineers, designers, owners and consumers to realize and accept the higher initial costs in an effort to seek a better return over time for the environment and oftentimes a better economic return as well.

Many other businesses are seeing "green" not only as a marketing opportunity for the company but as a financial opportunity as well (Ball 2002 and Vesilind, 2007). As the public demands more sustainable products and services, the businesses that have incorporated these practices will benefit tremendously. Other financial opportunities also arise from the tenants of sustainable practices such as increased profit from more efficient production, which lowers costs and increases profits (Vesilind, 2007). In the design and construction sector, sustainable structures are becoming more in demand and are a great selling point for potential clients and potential recruitment. They can also be profitable if system integration and planning is performed early in the design process (Allen, 2007). Sustainable buildings are increasing in demand because of the potential reduction in operation, energy, and maintenance costs which can result in fewer employee absences from an improved work environment (Ball, 2002).

The role of an engineer is to design a system that provides a function for the client based on various criteria and constraints for the project. Through interviews it has been found that engineers would like to introduce sustainable design into common practice for benevolent reasons, such as the morality behind it and preserving the future for their children (Vesilind, 2002). For years, it has been common practice for the engineers to minimize materials and consider efficiency into their design, which are both sustainable engineering practices, but this method must be taken to the next level (Kren, 2007).

The next level is to incorporate sustainable design into common practice. Unfortunately, for the engineer there are several barriers to the introduction of sustainable design into common design and construction practice. The main issue with the introduction of sustainable design into common practice is that the integrated design of the structure affects the environmental impact of the building, whereas the engineer is taught to break the analysis down and build it up (Coates, 1993).

3.2 - Ways to measure sustainability

In order for engineers to optimize their design for sustainability, first a way to measure and then compare sustainable aspects of sustainable design must be introduced (Field, 2007). Since the World War II era, the method used for decision making based on multiple criteria is the cost-benefit analysis. The cost-benefit analysis has endured because of its ease of use and simple monetary units.

The purpose of a sustainability assessment is to provide a comprehensive analysis of the impact of a building using several environmental indicators. Unfortunately, environmental impacts are not normally measured nor can be simplified to monetary units. Therefore, a different assessment methodology must be used and currently the most suitable analysis method for the environmental impact of a building is the Life Cost Analysis (LCA) method (Ding, 2006). The drawback behind the LCA based environmental assessment is the lack of economic analysis in most LCA tools, despite the reason for building development and the major constraint is economically based. These environmental impact assessments are then used to develop an optimal design and are then used as design guidelines or guides. It is important to consider the environmental impact of the assemblies and systems early in the conceptual design stage in order to more efficiently choose the most appropriate alternative, however current LCA tools require details from the engineers and designers that are only available near the end of the design stage. Unfortunately, at this point in the design stage, changes to the design scheme can be costly, in economy, time, and man-hours. This inherent problem is due to the nature of the LCA tools, which are used to analyze the environmental impact of the building, and not as a design tool (Ding, 2008).

3.3 - Generic Metrics and Eco Labeling

Another alternative to the detailed LCA methodology is what is known as "eco-labeling". This is the process of taking a set of prescriptive criteria and applying it to the project, which will result in a single overall score that is supposed to relate the sustainability of the project. There are several drawbacks to these programs as well. Typically eco-labeling uses a single metric such as energy, which is easily quantifiable and measurable. In other cases the metrics and criteria are often based on politically perceived values instead of real comparative data and even then the industries involved in the creation of the standards have them set to already attainable levels in order to reduce costs (Ball, 2002). Other times, the performance of one environmental impact area may be sacrificed for increased performance in another to achieve a higher level of perceived environmental value (Ding, 2008). Furthermore, this generic scheme fails to take into account local resources and technologies (Ball, 2002). Due to the uniqueness of each building project, one cannot be compared to another or even a baseline; it can only compete with itself since no other building has the unique situation of that particular location or use. An example of an eco-labeling program is the Energy Star rating for the efficiency of appliances.

3.4 - LCA and Comprehensive Building Assessment Tools

The first comprehensive building assessment program to include more than single dimension indicators, called BREEAM (Building Research Establishment Environmental Assessment Method), was developed in the early 1990's in the United Kingdom. In the United States the building assessment tool is known as LEED (Leadership Energy and Environmental Design) and was developed by the US Green Building Council. LEED uses a prescriptive criteria based approach to rating the environmental impact of buildings in five categories: sustainable site development, water savings, energy efficiency, materials selection, and indoor environmental quality (Ding 2008).   Most public projects now require LEED certification of silver or higher (Kren 2007). The LEED program is a prescriptive, generic approach and does not include a whole building analysis over the lifetime of the building, provisions that would allow for building comparisons or factor in repair, maintenance and demolition.

LCA methodology utilized by the building assessment tools typically adopts the Standard ISO 14000 process specifically designed for environmental analysis (Ball, 2002). The LCA methodology focus on "cradle to grave" analysis of all building components and energy consumed over the lifetime of the building and material. To simplify the analysis, the life cycle of the building is broken up into stages which are: the manufacture of materials, construction, operation, maintenance and repair, and demolition (Cole, 1996). If the variables that constitute each stage are independent of other stages, then each stage can be optimized and then each stage combined (Pushkar, 2005). One problem with the LCA method is the vast quantity and quality of data required for all levels of the analysis which can be difficult to both manage and acquire as well as definitive system boundaries which must be defined (Ball, 2002).

LCA tools that are available with databases for North America are BEES 2.0 (2007) and the Athena: Impact Estimator (2008). BEES 2.0, developed by the US Environmental Protection Agency (EPA), is a product comparison tool that uses LCA of various environmental impacts to compare material options. This program differs from most other LCA tools in that it only compares building products not the entire building or even building assemblies (Erlandsson, 2003). The database compares materials on several indicators including: global warming potential, acidification potential, eutrophication potential, fossil fuel depletion, habitat alteration, criteria air pollutants, human health, smog, ozone depletion, ecological toxicity, water intake, and indoor air quality (Lippiatt, 2007). The database utilizes a US average for comparison purposes.

While the material database is large and growing, currently there is no way to distinguish precast from cast in place concrete assemblies which may have an impact on the environmental impact of the material. Steel rebar is included in the concrete analysis and is assumed to be 100% recycled material and thus has no impact which may be an over generalization given the amount of reinforcing in many structures (Lippiatt, 2007). However, this tool was designed to offer an analysis of several materials on a comparative basis for design purposes and in this way makes this the only real design tool.

3.5 – Athena Impact Estimator

The Athena: Impact Estimator (2008) is a comprehensive building assessment tool using LCA methodology for analysis. The Impact Estimator Version 3 assesses buildings based on the following environmental indicators: primary energy use, solid waste, global warming potential, air and water pollution indexes as well as a weighted measure for resource extraction with potential measures to come in future versions. This program can be used for the development of several alternative designs and can handle up to five models for comparison. The program also currently supports several geographic regions, including several cities in the United States and Canada for use in the analysis. When the location is specified the program, it will adjust calculations to the appropriate power grid, resources, and average travel distances for the area. Regions currently available include: Halifax, Quebec City, Montreal, Ottawa, Toronto, Winnipeg, Calgary, and Vancouver in Canada, a US average, Pittsburgh, Minneapolis, Atlanta, and Orlando in the United States. The database is based mostly on information from the US Life Cycle Inventory database. While some detailed information is required to model buildings with this program, its usability as a comparison tool is powerful as several similar designs can readily be prepared and compared with the program package (Athena Institute, 2008).

For the environmental analysis, a bill of materials is formed from assemblies that are constructed within the program based on materials, geometry, and other specifications depending on the assembly or system type. The LCA is then performed on the bill of materials for each stage in the life cycle of the building referenced to the geographic region specified. The life cycle stages analyzed by this program are the extraction and manufacture of construction products, transportation, on site construction, maintenance and replacement, structural system demolition, and landfill transport. The intensity of repair and maintenance schedules can be adjusted depending on the type of building specified by the user. Owner operated buildings utilize a more rigorous maintenance schedule whereas the rental properties use a less intensive schedule.

There are limits to the analysis capabilities of the Athena Impact Estimator. First, the program is not an energy simulation program so operational energy requirements must be calculated by a third party program, however it does allow for the input of energy requirements based on fuel type, including electricity, natural gas, coal, as well as other fuel types for the building analysis. The program also does not recognize doors as part of the assembly, but the doors can be modeled as additional windows or neglected depending on the type of door used. The databases and modeling capabilities of the Athena Impact Estimator make it the most suitable program for a comprehensive building assessment for projects in the United States and Canada (Athena Institute, 2008).

3.6 - Sustainable Structural Design

It has already been stated that engineers want to incorporate sustainable design into their projects, that clients are demanding sustainable designs and that sustainable design makes good business sense. But how does the structural engineer incorporate sustainable practices into their design? The building must still perform for the lifetime of the structure and the engineer is still constrained by the overall building design of the architect, so what can the engineer do?

Since it is clear that the current design methodology cannot drastically change, one must look at areas where it can be amended. Currently, the design methodology is based on performance and governed by the requirements of design codes. Beams and columns are sized for strength to prevent collapse and failure at ultimate and deflections to resist cracking or large deformations under service loading. The engineer also takes into account economic and construction considerations such as using standard sizes and lengths of material and a repetitious design that increases the speed of construction. These performance considerations cannot change with the introduction of the additional sustainable design considerations. Furthermore, the economic and construction considerations are already "sustainable" concepts since they save time, money and resources. This occurs because steel and concrete producers can more efficiently produce mass quantities of standard sizes and when custom or a multitude of sizes are used, it requires more effort and time for the producer to manufacture this material. Furthermore, an increase in the number of section sizes on a construction site will increase construction time, effort as well as storage space for the construction material. So, while designing for the least weight can save resources that are a part of the section, additional resources in waste material, economy, time, and resources can offset the gain from the materials saved.

Sustainable structural engineering practice could also include the use of the design-build delivery method. The design-build delivery combined with the use of an integrated structural design and interoperable software can decrease construction time, increase efficiency, and reduce the number of change orders. This method also makes it easier for problem solving because the design and construction team can communicate more effectively, structural engineers can be more involved with other disciplines involved on the project and can take a more active leadership role. This method also brings the fabricators and suppliers in at an earlier date which can lead to earlier material acquisition, rapidly reducing delivery time (Allen, 2007).

The structural engineer must also be aware of the sustainable practices being used by other disciplines and any additional structural requirements these may put on the structure, such as green roof, utilization of the thermal mass of the building envelope, raised floors, and exposed structural members (Sullivan, 2008).

In addition to these considerations, each life cycle stage should be analyzed for how sustainable design can be incorporated into the structural system. The Athena Impact Estimator is a reasonably good program for helping to develop and demonstrate quantitatively the energy and resource consumption of a basic design. The program output can be used to project the completion of some of the LEED criteria such as resource management.

3.7 - Life Cycle Phases

The life cycle analysis takes the impact of each life cycle stage into account in the analysis. The stages used in this analysis are: extraction and manufacture, transportation, construction, operation, repair and maintenance, and demolition.

3.7.1 - Extraction and Manufacture

In this stage the structural engineer will specify the types, sizes and strength of materials used for the structural system. The most typical construction materials used are timber, steel and concrete. Each material has its own strengths and weaknesses both in terms of performance and sustainability. The use of reused or recycled materials can greatly reduce the amount of energy and materials used in the building envelope. Substitution of materials such as fly ash, or furnace slag as a pozzolanic substitution for Portland cement is an example of using the waste from one industry in the new product of another. Precast or preassembled systems will increase the environmental impact of the manufacture stage, however they will decrease the impact of the construction phase to a greater extent. This is possible because construction of precast pieces at the production plant saves time and space on the jobsite. Because the prefabricated pieces can be offloaded and assembled without taking the tools and time required to make the assembly onsite. Preassembled or precast assemblies also use less waste, are made to higher precision, and are more consistent in strength and specifications due to factory controls.

3.7.2 – Transportation

The effect of this stage varies by geographic location of the supplier, distributor, and project site as well as the materials and transportation method used. Use of local materials and labor can greatly reduce the impact of this stage by reducing the transportation distance between the manufacturer, distributor and the job site. With less distance between locations there is less environmental impact and energy consumption from the transportation vehicle. Different transportation methods also have different amounts of impact. Most materials are assumed to be moved by truck and although other modes of transportation such as trains and ships may be more efficient at moving larger loads, they are constrained by the rail and waterways that limit their mobility (Cole, 1999).

3.7.3 – Construction

As previously stated, utilization of precast or preassembled pieces can save time and space on a job site and can be built more efficiently with greater precision (Shaw, 2007). There is currently a lack of demand from the construction industry to reuse or use recycled materials (Ball, 2002). LEED points can be acquired from the use of recycled materials during construction as well as the reuse of materials and managing the waste during construction (Sullivan, 2008).

3.7.4 – Operation

The impact of this stage is when the building is in use and serving its intended purpose. This is the most consuming phase of the life cycle over the lifetime of the building and it is therefore critical to reduce the impact of this stage early in the design (Cole, 1996). Operational energy is typically not affected by the structural system as the effect of the thermal mass of the columns and beams is not enough for a noticeable effect. However, if the thermal mass of a concrete wall is used as part of a passive thermal control system, the sizing of this wall could be a structural concern (Cole, 1996).

3.7.5 - Repair and Maintenance

The repair and maintenance of the building is resource intensive because many materials used for the operation of the building will not last for the entire design life of the building and must be replaced (Cole, 1996). It is often assumed during a building assessment that these items will be replaced with identical new items despite the real possibility of improvements over the long design life of the building (Athena, 2008). From a structural engineering standpoint, it is necessary to design durable and lasting structures that require little maintenance (Allen, 2007). In cases where performance design is considered, it is recommended to design for minimal damage to most situations. This may increase the initial impact of the structure, but the maintenance and repair or even reconstruction will be reduced if such an event ever occurs (Allen, 2007).

3.7.6 - Demolition and Recycling

The life cycle stage where the structural engineer can have the most impact is the demolition stage. A new design methodology specifically targeting sustainability from this stage is known as "Design for Adaptability and Disassembly" (DfAD). In this methodology, the structure is designed in such a way that it can be adapted for various uses over its lifetime and when it is disassembled, the structural elements can be taken apart and immediately reused on another building or structure. A common reason for building demolition before the end of the design life is that the building can no longer service the need of the tenants. In order to avoid this pre-obsolescence, the structure should be over designed, if possible, to handle additional service loads from possible changes in building utility. Larger bays and longer spans also facilitate the adaptability of a structure. The DfAD method requires foresight and thinking not only about how the structure will be constructed and behave for years, but also how it will be deconstructed and used again. In order to facilitate this reuse, building should be designed with commonly sized structural elements, with few different sized elements used repetitiously and utilizing mechanical connections instead of welds or adhesives (Webster, 2007).

Reuse should be the preferred alternative to recycling as recycling typically consumes vast quantities of energy and it is only economical to recycle about 25% of a given product. Beyond this 25% cutoff it becomes prohibitive as energy consumption increases exponentially to attempt to recycle more material because it is harder to recycle, separate or acquire (Vesilind, 2007).

3.8 - Material Considerations

As previously discussed the three main building materials; timber, concrete and steel all have pros and cons in relation to both their strength, durability and sustainability.

3.8.1 – Timber

Timber’s main limitation is that it is not as strong as steel or concrete and that it must be grown. At the same time, because it is grown and cultivated from trees it can be considered a renewable resource. Timber also has a low embodied energy because it only needs to be cut and milled with simple tools. Several drawbacks to timber are that it can be adversely affected by humidity and that it is not used in structures greater than three stories. In research by the Athena project comparing steel, concrete and timber alternatives, it was found that for a generic three-story building the timber structure was the most sustainable (Cole, 1996).

3.8.2 – Concrete

Concrete is a commonly used structural material. All building foundations utilize reinforced concrete and many buildings and structures use it for the above ground structural elements as well. Concrete is appealing because it can be formed to shape, is strong, and most of its constituent materials are readily available everywhere. The fine and coarse aggregate and water that make up most of the concrete are ubiquitous and require very little energy to produce. The environmental impact from concrete is mostly from the Portland cement that holds the aggregates together. This impact comes from the energy consumed and the green house gas emissions from the production of clinker, a critical step to Portland cement production (Naik, 2008). However, a portion of the amount of Portland cement that is used in the concrete mix can be replaced with other pozzolanic materials such as fly ash, blast furnace slag, finely ground glass, crushed concrete, or waste gypsum board which are all waste products from other industrial processes (Webster, 2007). Pre-cast concrete structures are also typically faster to construct that steel structures despite hardening times (Sullivan, 2008). Pre-cast construction can greatly reduce construction time and increase uniformity while lowering impact due to the reuse of forms and other aspects of the pre-fabrication process (Shaw, 2007). In addition, cast in place concrete construction is constrained by the travel time from the ready mix center to the job site because of setting times, although admixtures may be used to control this to some degree (Cole, 1999). Another problem with using concrete is that it cannot be easily adapted or disassembled for reuse. This is because of the often large monolithic designs used and the mortar used to connect them, although precast elements may be reused if they were detailed to be disassembled during the initial design and construction.

3.8.3 – Steel

Steel is strong in both tension and compression making it more versatile than concrete. Even if concrete is the main construction material it will utilize steel for the reinforcement. Steel is easily recycled or reused but has high-energy costs in the manufacture of the material. Steel must also be protected from the corrosive effects of the environment to remain durable (Cole, 1996). Steel is used in long spans, which increase the adaptability of the building. Its relative lightweight allows for a reduction in the lateral support required in seismic regions. Steel is easily integrated with other systems, unlike concrete where it is possible to cut into the reinforcement or post tensioning. Minimum amount of waste is produced from the exact specifications that are available as well as a reduction in waste materials and labor from the lack of forms and shoring that are required for concrete. Steel is produced in a factory with high tolerances on its strength and dimensions and it has its full strength upon production. Lightweight steel also has advantages over timber construction, such as lightness, less waste, strength, no creep or changes in size from temperature or humidity (Sullivan, 2008).

3.9– Conclusions

There currently is no set standard or method of practice to follow to achieve sustainable design, even if there was, building design is so unique for each case that a set guideline or standard may not be applicable to all or most projects. In the current state of building design then, the engineer must ask, “which products are more sustainable?”, "how does one measure sustainability?" These are all important questions that need to be answered before progress towards a sustainable society can be made.

The following lists some of the strategies that can be applied to each Life Cycle stage.

Manufacture - Use of recycled or reused materials

Transportation - Use of local materials and resources

Construction - Use of pre-fabricated assemblies

Operation - Ensure proper insulation of the building envelope

Repair & Maintenance - Design of durable and maintenance free structures

Demolition - Design for members to be reused

As can be seen from the previous discussion, it is important to incorporate sustainable design into the structural engineering methodology both from economical and environmentally responsible viewpoints. Realizing that structural design considerations and strengths of structures cannot be compromised, it is therefore pivotal to develop an efficient design through the interdisciplinary cooperation and planning of the design and sustainable characteristics early in the building development. Furthermore, the use of each structural material has its own unique properties and considerations and should be used in a combination that would best suit the economy, durability, and sustainability of the structure.

Chapter 4 – LEED 4-H Center Case Study

4.1 - Introduction

Sustainable or "green" building projects are becoming more common in various areas across the country. Ohio's new 4-H Center on the campus of The Ohio State University (OSU) is one of the first projects in the central Ohio region and the first project on the OSU campus to be appraised for LEED certification. The project is also the one of first of its kind on a land grant university in the United States. The project consists of a five story office for the 20-25 full time employees of the Ohio 4-H Program of the University Extension program as well as a single story branch containing large meeting and classrooms for training and events (DOE, 2006). The LEED rating system is becoming more common for both public and private projects across the United States. Pictures of the completed 4-H Center can be seen in Figures 4.1 and 4.2.

Figure 4.1-Ohio 4-H Center-East View

Figure 4.2-Ohio 4-H Center-Northwest View

The LEED program was developed by the United States Green Building Council (USGBC) and rates the sustainability of building projects. This is done by meeting a set number of predetermined criteria and different levels of certification may result (USGBC, 2005). The center has applied for a silver LEED rating while attempting to earn 38 points through meeting various criteria of the LEED 2.2 version of the program (LEED Scorecard, 2008). Points are awarded for meeting criteria for sustainable design and construction practices in each of the five LEED categories: sustainable sites, water efficiency, energy and atmosphere, materials and resources, indoor environmental quality. Points are awarded for meeting specific criteria such as reduced energy consumption, use of recycled materials and limiting site impact during construction. The total number of points the project earns determines its rating level: certification, silver, gold, or platinum (USGBC, 2005).

Of the 38 points attempted in the project, 29 were related to the design and performance of the building while 9 were from sustainable practices implemented during the construction phase (LEED Scorecard, 2008). If all points that were attempted are awarded, then the project will achieve a LEED Silver rating (33-38 points). Upon actual certification, however, only 30 points were earned to reach the Certification level, one rating level below Silver (LEED Certification, 2008). Currently, the silver rating is required for new construction of publicly funded projects in many areas, including Ohio (Kren, 2007). The 4-H Center has incorporated many sustainable design features recognized by LEED into its design and construction. Here the project is presented as a case study of the application of Silver LEED rating on a new construction project.

4.2 - LEED Criteria

As previously stated there are 69 total possible LEED criteria that can be met. The list of criteria and the ones met by the 4-H Center can be seen in Figure 4.3. This section will go through the steps taken by design and construction team to achieve LEED certification.

LEED for New Construction v2.0/2.1

Ohio 4-H Center
Project # 10002973
Certification Level: Certified
December 3, 2008

30 Points Achieved — Possible Points: 69

Certified 26 to 32 points Silver 33 to 38 points Gold 39 to 51 points Platinum 52 or more points

Y		Sustainable Sites (6)	Possible Points: 14
Y	Prereq 1	**Erosion & Sedimentation Control**	
1	Credit 1	**Site Selection**	1
	Credit 2	**Development Density**	1
	Credit 3	**Brownfield Redevelopment**	1
1	Credit 4.1	**Alternative Transportation**, Public Transportation Access	1
1	Credit 4.2	**Alternative Transportation**, Bicycle Storage & Changing Rooms	1
	Credit 4.3	**Alternative Transportation**, Alternative Fuel Vehicles	1
1	Credit 4.4	**Alternative Transportation**, Parking Capacity & Carpooling	1
	Credit 5.1	**Reduced Site Disturbance**, Protect or Restore Open Space	1
1	Credit 5.2	**Reduced Site Disturbance**, Development Footprint	1
	Credit 6.1	**Stormwater Management**, Rate & Quantity	1
	Credit 6.2	**Stormwater Management**, Treatment	1
	Credit 7.1	**Landscape & Exterior Design to Reduce Heat Islands**, Non-Roof	1
1	Credit 7.2	**Landscape & Exterior Design to Reduce Heat Islands**, Roof	1
	Credit 8	**Light Pollution Reduction**	1

Y		Water Efficiency (4)	Possible Points: 5
1	Credit 1.1	**Water Efficient Landscaping**, Reduce by 50%	1
1	Credit 1.2	**Water Efficient Landscaping**, No Potable Use or No Irrigation	1
	Credit 2	**Innovative Wastewater Technologies**	1
1	Credit 3.1	**Water Use Reduction**, 20% Reduction	1
1	Credit 3.2	**Water Use Reduction**, 30% Reduction	1

Y		Energy & Atmosphere (3)	Possible Points: 17
Y	Prereq 1	**Fundamental Building Systems Commissioning**	
Y	Prereq 2	**Minimum Energy Performance**	
Y	Prereq 3	**CFC Reduction in HVAC&R Equipment**	
1	Credit 1.1	**Optimize Energy Performance**, 15% New / 5% Existing	1
1	Credit 1.2	**Optimize Energy Performance**, 20% New / 10% Existing	1
1	Credit 1.3	**Optimize Energy Performance**, 25% New / 15% Existing	1
	Credit 1.4	**Optimize Energy Performance**, 30% New / 20% Existing	1
	Credit 1.5	**Optimize Energy Performance**, 35% New / 25% Existing	1
	Credit 1.6	**Optimize Energy Performance**, 40% New / 30% Existing	1
	Credit 1.7	**Optimize Energy Performance**, 45% New / 35% Existing	1
	Credit 1.8	**Optimize Energy Performance**, 50% New / 40% Existing	1
	Credit 1.9	**Optimize Energy Performance**, 55% New / 45% Existing	1
	Credit 1.10	**Optimize Energy Performance**, 60% New / 50% Existing	1
	Credit 2.1	**Renewable Energy**, 5%	1
	Credit 2.2	**Renewable Energy**, 10%	1
	Credit 2.3	**Renewable Energy**, 15%	1
	Credit 3	**Additional Commissioning**	1
	Credit 4	**Ozone Depletion**	1
	Credit 5	**Measurement & Verification**	1
	Credit 6	**Green Power**	1

Y		Materials & Resources (4)	Possible Points: 13
Y	Prereq 1	**Storage & Collection of Recyclables**	
	Credit 1.1	**Building Reuse**, Maintain 75% of Existing Shell	1
	Credit 1.2	**Building Reuse**, Maintain 100% of Shell	1
	Credit 1.3	**Building Reuse**, Maintain 100% Shell & 50% Non-Shell	1
	Credit 2.1	**Construction Waste Management**, Divert 50%	1
	Credit 2.2	**Construction Waste Management**, Divert 75%	1
	Credit 3.1	**Resource Reuse**, Specify 5%	1
	Credit 3.2	**Resource Reuse**, Specify 10%	1
1	Credit 4.1	**Recycled Content**, Specify 5%	1
1	Credit 4.2	**Recycled Content**, Specify 10%	1
1	Credit 5.1	**Local/Regional Materials**, 20% Manufactured Locally	1
1	Credit 5.2	**Local/Regional Materials**, of 20% Above, 50% Harvested Locally	1
	Credit 6	**Rapidly Renewable Materials**	1
	Credit 7	**Certified Wood**	1

Y		Indoor Environmental Quality (8)	Possible Points: 15
Y	Prereq 1	**Minimum IAQ Performance**	
Y	Prereq 2	**Environmental Tobacco Smoke (ETS) Control**	
1	Credit 1	**Carbon Dioxide Monitoring**	1
1	Credit 2	**Ventilation Effectiveness**	1
	Credit 3.1	**Construction IAQ Management Plan**, During Construction	1
	Credit 3.2	**Construction IAQ Management Plan**, Before Occupancy	1
	Credit 4.1	**Low-Emitting Materials**, Adhesives & Sealants	1
	Credit 4.2	**Low-Emitting Materials**, Paints	1
1	Credit 4.3	**Low-Emitting Materials**, Carpet	1
	Credit 4.4	**Low-Emitting Materials**, Composite Wood & Agrifiber Products	1
1	Credit 5	**Indoor Chemical & Pollutant Source Control**	1
	Credit 6.1	**Controllability of Systems**, Perimeter	1
	Credit 6.2	**Controllability of Systems**, Non-Perimeter	1
1	Credit 7.1	**Thermal Comfort**, Comply with ASHRAE 55-1992	1
1	Credit 7.2	**Thermal Comfort**, Permanent Monitoring System	1
1	Credit 8.1	**Daylight & Views**, Daylight 75% of Spaces	1
1	Credit 8.2	**Daylight & Views**, Views for 90% of Spaces	1

Y		Innovation & Design Process (5)	Possible Points: 5
1	Credit 1.1	**Innovation in Design**: Green Building Education	1
1	Credit 1.2	**Innovation in Design**: WEc3	1
1	Credit 1.3	**Innovation in Design**: SSc5.2	1
1	Credit 1.4	**Innovation in Design**: Green Housekeeping	1
1	Credit 2	**LEED® Accredited Professional**	1

Figure 4.3-LEED Certification of the Ohio 4-H Center

4.2.1 - Sustainable Sites (SS)

The sustainable sites category focuses on reducing the development footprint of the site by taking into account site disturbance, excess water runoff, and transportation needs (USGBC, 2005). In the case of the 4-H Center measures were taken to limit site disturbance, encourage sustainable transportation alternatives, and manage stormwater quantity and treatment (Morelli, 2006).

The prerequisite for earning points in the sustainable sites category of the LEED program is to implement an Erosion and Sediment control plan. This plan outlines measures taken to limit soil loss from erosion and rainfall, and sedimentation (USGBC, 2005). In order to meet this criterion, several best management practices, such as covering exposed dirt and material and the use of water sprays were implemented to reduce the sedimentation of the water runoff. Furthermore, temporary fences were placed around the trees and vegetation that were to remain after the construction which increased the amount of intact groundcover and limited the amount of excess runoff in and around the construction site (DOE, 2006).

The first LEED credit earned in the sustainable sites category is for site selection (SS Credit 1) (LEED Scorecard, 2008). The 4-H project site is located on the Chadwick Arboretum tree reserve and research center. The site location is juxtaposed existing poultry buildings and a nearby research pond as seen in Figure 4.4 (DOE, 2006).

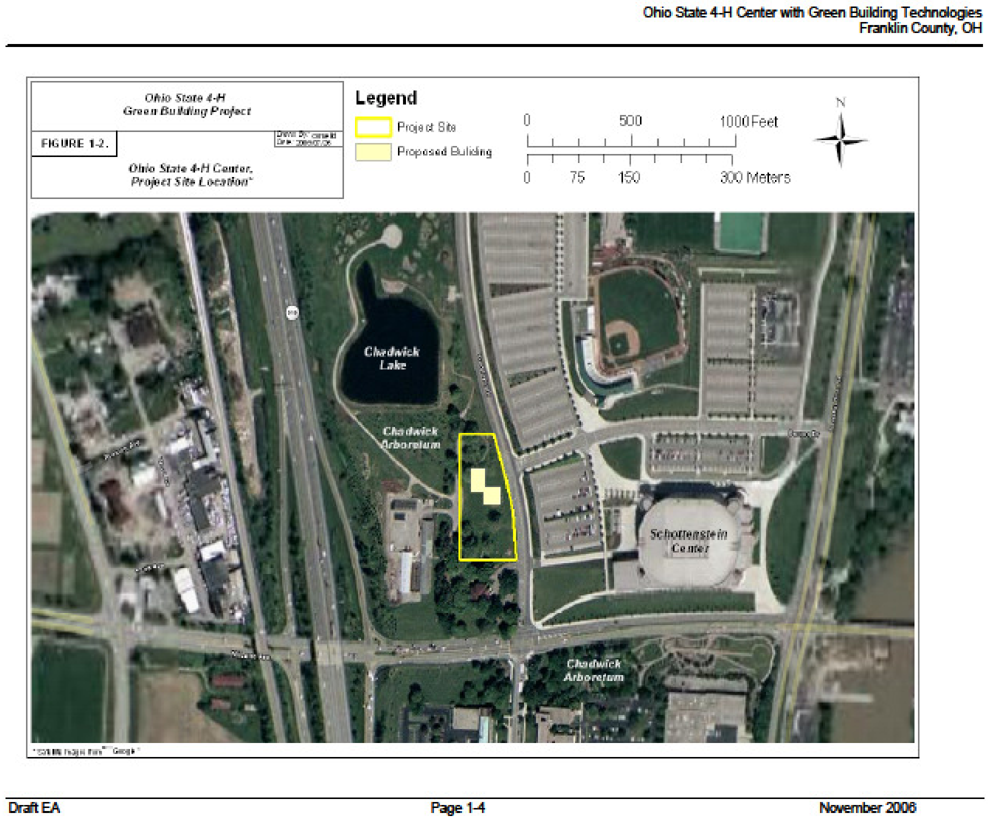


Figure 4.4-Site of 4-H Center (DOE, 2006)

Proximity to such facilities is important because of the functionality of the building as the 4-H Center that will utilize these facilities regularly. Because of the location on the arboretum, site development was carefully planned and executed. This included a tree removal plan that was followed for the site, which indicated specific trees to be removed and which trees were to remain. In general, well-developed trees were spared outside of the building footprint whenever possible (Morelli, 2006). This tree removal plan can be seen in Figure 4.5.

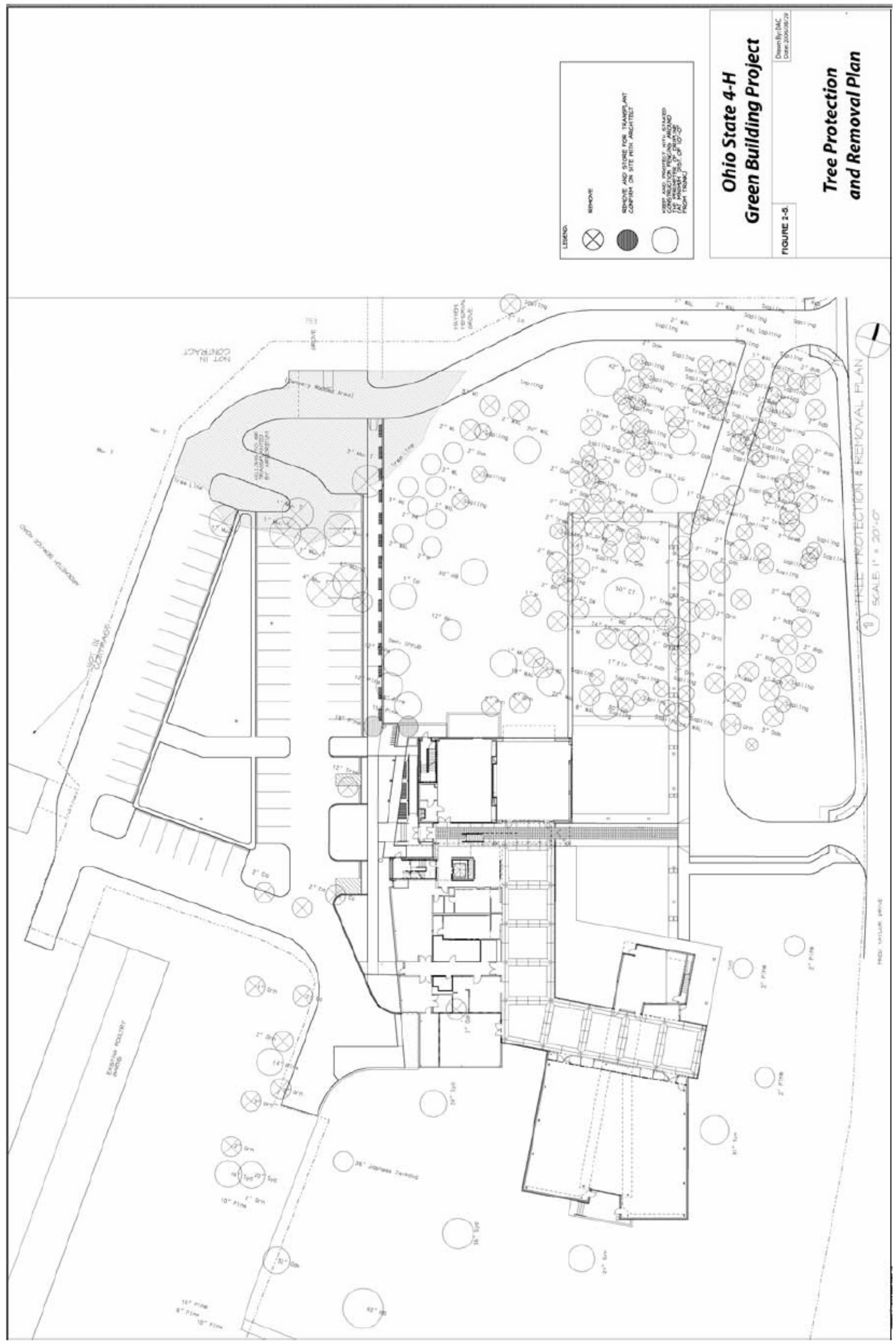


Figure 4.5-Tree Removal Plan (DOE, 2006)

An Environmental Assessment for the project carried out by the Department of Energy concluded that due to previous development in the area (including the Schottenstein Center, State Route 315, now demolished Dakan Hall and existing poultry barns) development on the site would have no significant impact due to the already disturbed soils in the area and the landscape was man made and consists groupings of vegetation with the majority of the project site on maintained campus lawn (DOE, 2006).

Sustainable Site Credit 4 focuses on encouraging the use of alternative and more sustainable transportation methods such as public transportation and bicycles (USGBC, 2005). The 4-H Center is located just west of Jesse Owens Memorial Stadium, Davis Baseball Stadium, Jerome Schottenstein Center and other varsity athletic facilities each with abundant nearby parking as well as campus bus and Columbus bus lines that run continuously.

SS Credit 4.1 is earned by locating the building project site within ¼ mile of at least two bus lines. The closest bus stop to the 4-H Center is about 1/10 mile to the south on Lane Avenue. The station is on a Central Ohio Transit Authority (COTA) bus line. The next closest COTA station on a different line is about 2/10 of a mile to the south at the corner of Fyffe and Woodruff Avenue. A map of the area surrounding the 4-H Center Location can be seen in Figure 4.6.

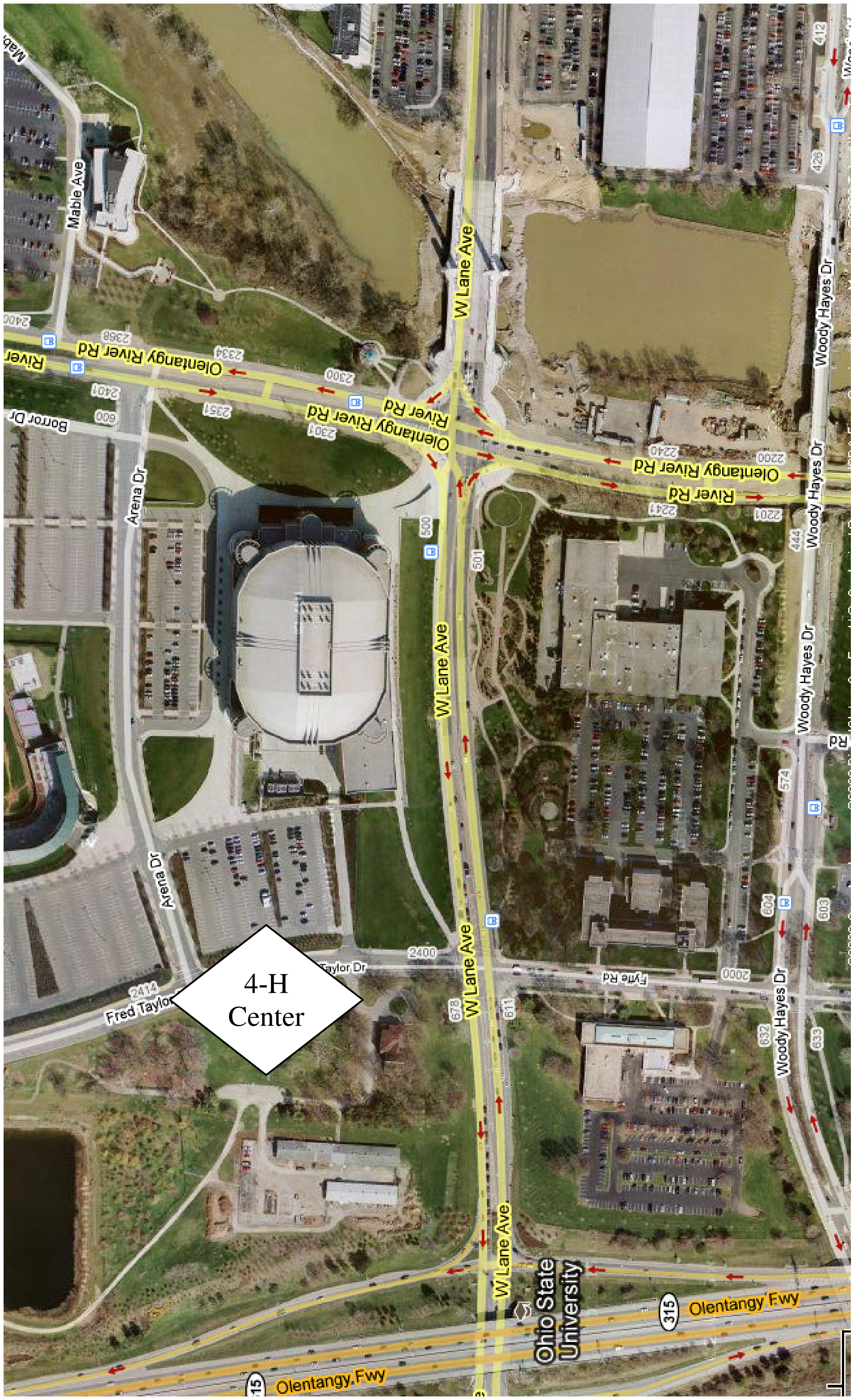


Figure 4.6-Map of the Ohio 4-H Center Area including Bus Stops (Google Maps)

SS Credit 4.2 can be earned by providing secure bicycle storage and changing facilities for building users. Secure storage or bike racks are required for 5% of all users as measure during peak times and changing facilities for 0.5% of the number of full time occupants (USGBC, 2005). The 4-H Center has two racks which can adequately secure four bicycles and a changing and shower room located near the rear entrance on the first floor which exceeds the requirement for credit of the 20-25 full time employees (the required capacity is for 1-1.25 bikes) (Morelli, 2006 and DOE, 2006).

SS Credit 4.4 is earned by limiting the buildings parking capacity and encouraging the use of carpools (USGBC, 2005). The 4-H Center is situated across the street from various athletic facilities with adequate parking available for building occupants which enabled designers to reduce the size of the parking lot. In addition, some of the spaces located closer to the rear entrance are designated as carpool only in an effort to reduce the number of total vehicles (Morelli, 2006). In consideration of the predevelopment case, the full time employees who work in the building will not be counted as new commuters because they are simply moving from their offices from other campus buildings (the previous site was located less than a quarter mile to the south) (DOE, 2006).

Sustainable Site credit 5.2 focuses on reducing site disturbance and the development footprint as well as providing green space comparable to the development area (USGBC, 2005). The 4-H Center project is a 5.6 acre site and 1.4 acres was developed for the building (0.4 acres), parking lots and driveways (DOE, 2006). The remaining 4.2 acres was landscaped using native vegetation and trees some of which were transplanted from areas on the site within the building footprint (DOE, 2006). New native trees were planted to augment and replace the ones lost from construction in and around the project site to contribute to the surrounding landscape and arboretum. During the construction phase, the impact area was reduced by fencing around the driveway roads which encircle the building thereby limiting disturbance of the other nearby area and facilities (Morelli, 2006). The boreholes from the geothermal heating and cooling system were located under the parking lot to limit additional site disturbance and the soil removed from the boreholes were used for site grading (DOE, 2006).

Credit for reducing and treating stormwater runoff on the site and into existing streams and systems can be earned under SS credit 6. SS credit 6.1 focuses on quantity control of excess runoff from rainfall events after the development. Development increases the amount of impervious surface area which increases the excess runoff that would have otherwise been infiltrated into the groundwater system (USGBC, 2005). The 4-H center is located on previously undeveloped land with nearby previous development which means that the amount of pre-development imperviousness is small so the LEED requirement is that the post development discharge rate and quantity do not exceed the predevelopment rate and quantity. The preexisting conditions of the site have surface runoff flows to the east towards Fred Taylor Drive and to the north to a grass lined shallow swale to Chadwick Lake which can be seen in Figure 4.2. To satisfy the criterion, the north end of the site is graded so that excess flow will be moved towards the road to existing catch basins as was the case prior to development (Morelli, 2006). The roof is drained to the green area to the north of the building to flow towards these same catch basins. The parking lot is graded toward a central pervious walkway composed of crushed tile above a draining base and finally an aggregate base layer to promote infiltration. SS credit 6.2 is for efforts to control the quality of the excess runoff by promoting infiltration through the ground (Morelli, 2006). Additionally, water encountered during borehole drilling was stored in a detention pond onsite until the water is clarified (DOE, 2006). Upon final certification, the project was not given credit for criteria 6.1 or 6.2.

SS Credit 7.2 is earned by reducing the absorbance of solar energy through the roof through the use of a vegetative covering or a reflective material (USGBC, 2005). The 4-H Center installed a white reflective roof material in an effort to reflect as much solar radiation as possible (Hunt, 2008). This reduces the amount of heat absorbed through the roof and helps the building to maintain a steady temperature throughout the day. Because the temperature is steady, the heating and cooling system does not consume as much energy by attempting to maintain a constant temperature.

SS Credit 8 focuses on the reduction of light pollution through careful placing of interior lighting, timing schedule and exterior lighting with a limited luminescent range (USGBC, 2005). To earn the point for this credit, the 4-H facility had planned to have only the necessary standard campus light poles lining the front drop off driveway and the rear parking lot. There is no exterior building illumination at night and lights are automatically shut off after normal business hours to minimize light pollution and energy consumption (Morelli, 2006). Despite these programs the 4-H Center did not meet the requirements for this criterion.

4.2.2 - Water Efficiency (WE)

Points are awarded in the category of Water Efficiency for reducing the amount of water used for irrigation and plumbing services and maximizing use of grey water or non-potable sources whenever possible (USGBC, 2005). The 4-H Center is earning credits in this category by using water efficient landscaping, waterfree urinals and dual flush mode water closets (Morelli, 2006).

Water Efficiency Credit 1 is for the use of water efficient landscaping utilizing a strategy that reduces the potable water consumption by 50% (WE credit 1.1) or by using non-potable water for irrigation (WE credit 1.2) (USGBC, 2005). To meet this criterion, the landscape surrounding the 4-H Center uses local plants and vegetation that do not require irrigation. Furthermore, because of the reduced site disturbance, many indigenous plants were able to be transplanted for the final design, further reducing the need for an irrigation system (Morelli, 2006).

Water Efficiency Credit 3 focuses on reducing the burden on the municipal water supply by reducing water consumption by 20% (USGBC, 2005). To maximize water efficiency, sensor operated sinks, water free urinals, sensor operated and dual flush mode water closets were specified in the design to reduce water consumption (Morelli, 2006). These systems reduce the amount of potable water used throughout the facility, thus reducing the burden on the local water supply.

4.2.3 – Energy and Atmosphere (EA)

The third LEED category is Energy and Atmosphere. This category focuses on strategies to reduce energy consumption and green house gas emissions. Points are awarded in this category for commissioning a design professional to develop the energy systems, utilization of renewable energy sources, optimization of energy system performance and use of renewable energy sources (USGBC, 2005).

This category has three prerequisites that must be satisfied in order to earn points in this category. The first is commissioning of the building energy systems, meaning that the systems were tested and evaluated based on performance. In the case of the 4-H Center, W.E. Monks & Co. designed both the electrical and mechanical systems. The second prerequisite is for the design to comply with the mandatory provisions of ASHRAE/IESNA Standard 90.1-2004 and other prescriptive and performance requirements of the same standard in order to demonstrate compliance with minimum energy efficiency standards. The third prerequisite is the use of non-CFC (Chlorofluorocarbons) based refrigerants in any new HVAC&R systems (USGBC, 2005). Since the mid 1990's, no new refrigerant equipment has been available that is CFC-based, so no equipment was installed in the 4-H that did not meet this criterion (Opitz, 2006).

Energy and Atmosphere credit 1 can be achieved by demonstrating improvement in energy savings above the prerequisite baseline (USGBC, 2005). Up to 10 points can be earned under this credit by reducing energy consumption by 42% compared to the ASHRAE baseline as measured through an entire building energy simulation. Building energy simulation tools such as DOE are available for this type of analysis. Another option to earn credit in this category is to follow the prescriptive compliance path delineated by the Advanced Buildings Core Performance Guide 2004, however, under this option a maximum of 5 points can be earned. The Department of Energy Environmental Assessment estimates a 30% increase in energy saving which if a building simulation was performed for the project, 6 LEED points could be obtained (USGBC, 2005, and DOE, 2006).

The 4-H Center uses a geothermal heating and cooling system that maintains a constant temperature throughout the facility without the use of traditional HVAC systems. The geothermal heating and cooling system is composed of pipes driven deep into the ground where the temperature is constant and water is pumped through the system to either warm or cool the building by either releasing or absorbing heat in the building (Hunt, 2008). Boreholes were connected with u-loops and the top and bottom to create nine closed loops of eight boreholes each with its own pump system. There is no mechanical equipment on the roof, which increases the longevity and efficiency of those systems (DOE, 2006). The 4-H center's geothermal heating and cooling system was vital in order to achieve this increase in energy performance and reduction in operating costs. Other factors, such as high reflective roof materials, use of natural light and after hours lighting control schemes were also implemented to increase energy efficiency throughout the building (Morelli, 2006). Additionally, installing the proper amount of insulation in the building envelope is one of the best ways to reduce energy consumption. However, if the insulation is too thick, there is too little transfer of heat through the thermal mass leaving the HVAC system to support the thermal environment solo. If the insulation is too thin, the HVAC system must compete with the infiltration of the outside environment to control the thermal environment (Mithraratne, 2003). The 4-H Center features exterior walls typically composed of brick, an air gap, weather barrier, densglass sheathing, 6 inch metal stud wall with R-19 batting insulation, vapor barrier, and gypsum board (Morelli, 2006). Upon final examination, the 4-H Center had an energy optimization of 25%, qualifying for 3 LEED points (LEED Certification, 2008).

4.2.4 - Materials and Resources (MR)

The Materials and Resources category focuses on the use of recycled or local materials and the reduction of waste from construction. Construction is one of the most resource consuming industries in the world and reusing or using recycled materials can greatly reduce the amount of raw materials consumed annually.

The required prerequisite for earning points in this category is the installation of recycling collection and storage containers throughout the facility. The 4-H Center has recycling bins located in various locations around the facility in common areas such as near vending machines (Morelli, 2006).

Materials and Resources credit 2 can be earned by reducing construction waste and debris by 50% (an additional point is earned if construction waste is reduced by 75%) through the use of recycling and salvage programs. The 4-H Center planned to recycle at least 50% of its construction debris to earn this credit (DOE, 2006). Upon final certification, however, the project did not qualify for this category (LEED Certification, 2008).

MR Credit 4 and 5 under are designed to increase the demand for recycled and local or regional materials in the construction industry, respectively. A calculation of the amount of recycled material in an assembly is determined by the weight fraction of recycled content. This fraction is then multiplied by the cost of the assembly to give the cost of the recycled content by weight. Recycled or regional materials should be chosen so that the recycled content constitutes 10% (an additional point is earned for 20% total recycled or regional content) of the total value of materials for the project. Calculations and percentages of the total amount of material is the same for MR credit 5 concerning the use of local or regional materials. Local and regional materials are defined as materials that have been extracted and manufactured within 500 miles of the jobsite. Columbus' central Midwestern location makes this criterion fairly easy to meet, with Pittsburgh, Cleveland, Detroit well within the 500 mile range. The steel superstructure of the 4-H Center used approximately 282 tons of structural steel. The steel was comprised of at least 90% recycled material coming from domestic mills using an Electric Arc Furnace (EAF) (DOE, 2006).

4.2.5 - Indoor Environmental Quality (IEQ)

The next to last category is Indoor Environmental Quality. This category focuses on providing a healthy and comfortable indoor environment for building occupants. Points can be earned in this category by monitoring CO^2 levels, use of low emitting materials, and providing and monitoring thermal comfort.

There are two prerequisites that must be satisfied for this category. The first prerequisite is that the HVAC system must meet the minimum ventilation requirements for Acceptable Indoor Air Quality as dictated by ASHRAE 62.1-2004. The second prerequisite is to minimize occupants to tobacco smoke within and immediately outside the building (USGBC, 2005). The second prerequisite is already fulfilled within the building because the state of Ohio has a law and Ohio State University has a policy against smoking within buildings (OSU Policy 7.20, 1996).

Environmental Quality (EQ) credit 1 can be earned for the monitoring of CO^2 levels within the building in order to promote occupant health and safety (USGBC, 2005). The 4-H Center uses CO^2 monitors to control the ventilation system. The CO^2 sensors adjust the ventilation system to maintain proper CO^2 levels taking into account the amount of people in the building. This means that when the building is not in use, the building ventilation system maintains minimum operational levels for its operation and then turns on once the building is occupied (DOE, 2006).

EQ credit 2 is for increased ventilation effectiveness which can be achieved by increasing outdoor air ventilation rates to at least 30% above the minimum required by ASHRAE (USGBC, 2005). As previously stated, the ventilation system monitors the CO^2 levels within the building and adjusts to maintain the desired ventilation rate (DOE, 2006).

EQ credit 4 can be earned by using low emitting materials during construction to promote both builder and occupant health. Up to 4 points can be earned in this credit and its subsections by using low emitting adhesives and sealants (EQ credit 4.1), paints and coatings (EQ credit 4.2), carpet systems (EQ credit 4.3), and composite wood and agrifiber products (EQ credit 4.4) in the construction of the facility (USGBC, 2005). In the 4-H center, low VOC carpeting was used throughout the facility and credit was earned for 4.3 (LEED Certification, 2008). Additionally, steps were taken to ensure that a rupture in the geothermal boreholes would not adversely affect the environment. To accomplish this, a particular anti freeze mixture was chosen that would not be harmful to the environment should a rupture occur. A solution of 80% water and 20% Dowfrost HD (Registered TM) heat transfer fluid was used in the closed loop system because of its low effect of its primary component, propylene glycol, on the natural environment compared to alternative mixtures. The boreholes were also backfilled with bentonite grout which adds additional protection to the threat of rupture, aids in heat transfer and reduces the hydraulic conductivity in the vertical boreholes. Each set of 8 boreholes is its own closed loop system as well, which reduces the amount of solution that could be expelled in case of rupture in any one pipe. The system also has a low pressure cutoff valve where the system is shutdown if pressure drops in the system (DOE, 2006).

EQ credit 5 focuses on controlling and limiting indoor chemicals and pollutants entering the building as well as the ventilation of spaces where harmful materials are stored (USGBC, 2005). The 4-H Center uses grated entryways to prevent dirt and debris from being brought into the building. Additionally, in order to remove the fumes built up from harmful chemicals the janitorial closets are ventilated (Morelli, 2006). Mechanical systems are located in the basement to reduce radon exposure and no assignable space is located in that space. The 4-H Center also uses soy-based cleaning supplies and products when possible and is able to minimize the use of pesticides with the incorporation of native plants into the landscape (DOE, 2006). All of these measures reduce the amount ofchemical exposure to building occupants and the environment.

EQ credit 7 is earned by providing a thermally comfortable work environment. One point can be earned for design in compliance with ASHRAE Standard 55-2004 and an additional point may be earned for verification of the actual comfort level. This is done through a survey of building occupants 6 to 18 months after completion as well as the ability to adjust the climatic controls accordingly (USGBC, 2005).

EQ credit 8 attempts to create a connection between building occupants and the outdoors by controlling the daylight and views to the outside. In order to earn the credit, 75% of all interior spaces should have a midday illumination of at least 25 foot-candles.

An additional point may be earned if 90% of all workspaces are in direct line of sight to exterior windows (USGBC, 2005). The 4-H Center was able to meet these criteria using an open office floor plan with large window bays and high ceilings. In addition to the common floor space, the private offices and other rooms all have windows. This not only provides the line of sight and illumination required, but also saves energy through the use of natural lighting (Morelli, 2006).

4.2.6 - Innovation in Design (ID)

A sixth category is included which is more all encompassing and designed to take into account innovations in sustainable design that are not specifically addressed in the other categories. Innovation in Design (ID) credit 1 can be earned by applying innovative techniques that enhance performance above addressed LEED requirements or in areas not specified by the LEED program. This includes continuing to educate the public about green buildings (1 point). In addition, 3 credits were earned for innovation in design and for "green housekeeping" (LEED Certification, 2008). ID credit 2 can be earned if at least one principal member of the project team is a LEED accredited professional (USGBC, 2005). For the 4-H Center project, several LEED APs worked on the project both from Lincoln Street Studio and W.E. Monks & Co.

4.3 –Summary and Conclusions

As stated previously, the 4-H Center earned 30 LEED points to earn the Certified certification level. This achievement was 3 points behind of the initial Silver level that was applied for at 38 points. This was caused by not achieving points regarding stormwater management, light pollution reduction and construction waste management (final total). It is recommended that on future projects, further accountability for the stormwater and construction waste be taken. Although it is possible that due to the location of existing lines and structures it was not economical or feasible to reach the required level of stormwater management. Furthermore, it is also possible that due to the campus lighting policy designed to increase the safety of its students and visitors that this mitigated any effect from light pollution reduction.

As seen from this case study, it is possible to design and construct new buildings and facilities with sustainable characteristics on a major campus in an urban environment. It has also been shown that with certain design considerations, the building can conserve operating energy, in this case with the underground thermal system. This enables the building to operate on electricity alone, which, depending on the area and provider can come from a variety of renewable resources.

This case study outlined the specific LEED criteria attempted and achieved by the 4-H Center project on the campus of the Ohio State University. The point by point evaluations of the criteria were set forth in a categorical matter matching the LEED program for new construction.

Chapter 5 - Quantitative Sustainability Model of the Ohio 4-H Center

5.1 - Objectives

The objective of this project is to define the quantitative sustainability of a campus building using commercially available software. This is accomplished by using a life cycle cost analysis as applied to a variety of economic indicators. The other goal of this research is to explain the methodology and applicability of modeling buildings in these software packages in order to develop more sustainable structures.

5.2 – Background Research

This section discusses some of the research performed in this area rfollwing the initial discussion of the review of journals.

5.2.1 - Programs Available

There are several programs available that are based on the Life Cycle Analysis (LCA) of a building in relation to its sustainable characteristics. Each of these programs has been developed from databases of the environmental effects of various products and assemblies at each stage of the life cycle of the product or building, so it is important to select a program that has the most applicable database for the region of the project. An article by the Royal Melbourne Institute of Technology (2001), entitled ”Background Report LCA Tool, Data and Application in the Building and Construction Industry”, categorizes each type of LCA and sustainability program available at the time and offers a comparison chart that contrasts the features of each program. Selections of the programs applicable or used in the United States are discussed further in the next section.

5.2.1.1 - LEED

While the Leadership in Energy and Environmental Design by the U.S. Green Building Council is a rating system often utilized in the United States, it is criteria based, meaning that as long as the building satisfies certain criteria, it can increase its ratings. This rating scheme does not easily allow for comparisons of several designs as points do not all contain the same "amount" of sustainability. Additionally, this system does not take into account the life cycle costs of materials and maintenance over the lifetimes of both the material and the building. So, while the LEED system is easy to use and is becoming the standard system for the United States, it does not yield quantifiable information regarding the sustainability of buildings and structures.

5.2.1.2 - BEES

The Life Cost Analysis or LCA software for the United States is produced by the United States Environmental Protection Agency (EPA). However, the BEES (Building for Environmental and Economic Sustainability) program differs from the other whole building calculators as this program compares the sustainable characteristic of building materials. This means that the program can only be used to compare building components and not the whole building or building assemblies. So the BEES program is useful for material comparisons, which is an important step in developing sustainable structures, but not in the development for creating a model for an entire building, so this program was not used for the analysis in this study.

5.2.1.3 - Athena

The Athena Institute of Merrickville in Ontario, Canada has developed a LCA tool for whole buildings and assemblies called the Athena Impact Estimator. This program allows the user to generate whole building models utilizing structural and envelope assemblies. While energy consumption is not part of the analytical program itself, Athena can accept and will integrate energy consumption data from outside sources on a yearly basis from a variety of fuel sources. The Athena program was developed in Canada and has the capability of placing the project in various Canadian metropolises and the newer versions contain data for cities of the United States of America, such as Los Angeles and Pittsburgh as well as a national average. (Athena Institute, 2008) Because of the analytical capability of the Athena program and the geographical applicability, the Athena Impact Estimator version 3.03 was chosen to develop the model of 4-H Center building in this project.

One of the main objectives of this project is to model the quantifiable characteristics of the 4-H Center building using LCA. The 4-H Center on the campus of the Ohio State University was chosen because it was recently completed in 2008 and the project was certified using the LEED rating system. In addition, an analysis of this building should give a baseline for the LEED rating of “Certified” obtained by this structure. The LEED system as applied to the 4-H Center was further discussed in Chapter 4.

5.3 - Methodology

This section contains the method in which the inputs into the Athena program were made as applied to the 4-H Center. After a review of the plans and obtaining the

Athena Impact Estimator software from the Athena Institute and reading their tutorial on its general use, the software was installed on a personal computer (this was not installed on a laboratory computer due to licensing limitations and administrative locks on the installation of programs in the laboratory). The following is a walkthrough of the steps that were taken to develop the model for the 4-H Center. Note that 4-H Center has a five-story building and a one-story building with meeting rooms. Only the five story tower was considered for this project as it represents the main building occupancy.

5.3.1 – Creation of a New Project in Athena Impact Estimator

First the program is opened and then "File→New" is selected to start a new project. Then the information regarding the project name, location, gross floor area, type of institution, building lifetime and units are input into the form as shown in Figure 5.1.

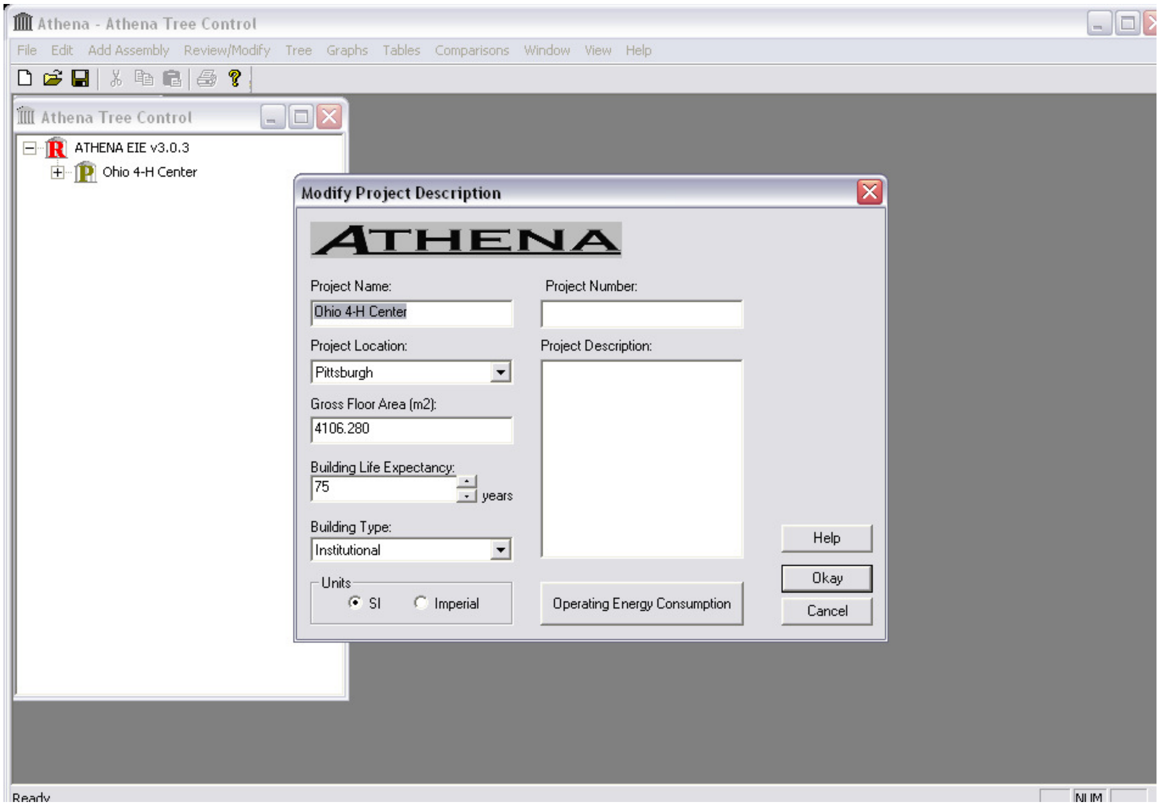


Figure 5.1-New Project Input in Athena Impact Estimator

The location chosen for this project was Pittsburgh because it is the closest available city to Columbus, Ohio in this, version 3.03, of the program. The gross floor area was calculated from a floor plan drawing in AutoCAD using the area feature. This plan or "small building plan" was available electronically from the Facilities, Operation, and Development (FOD) Department of the Ohio State University. The life expectancy for this project was estimated at 75 years given the relative longevity of buildings on the campus of the University. The building type chosen was institutional because that is the building type and this parameter becomes important as it sets the maintenance and repair schedule for the model. Imperial units also known as the US Customary System were chosen because this was the measurement system used for the construction documents.

The next step starting a new project is to input the annual building energy use by clicking on the "Operating Energy Consumption" button on the form. The energy consumption by fuel type is input on an annual basis into the form as can be seen in Figure 5.2.

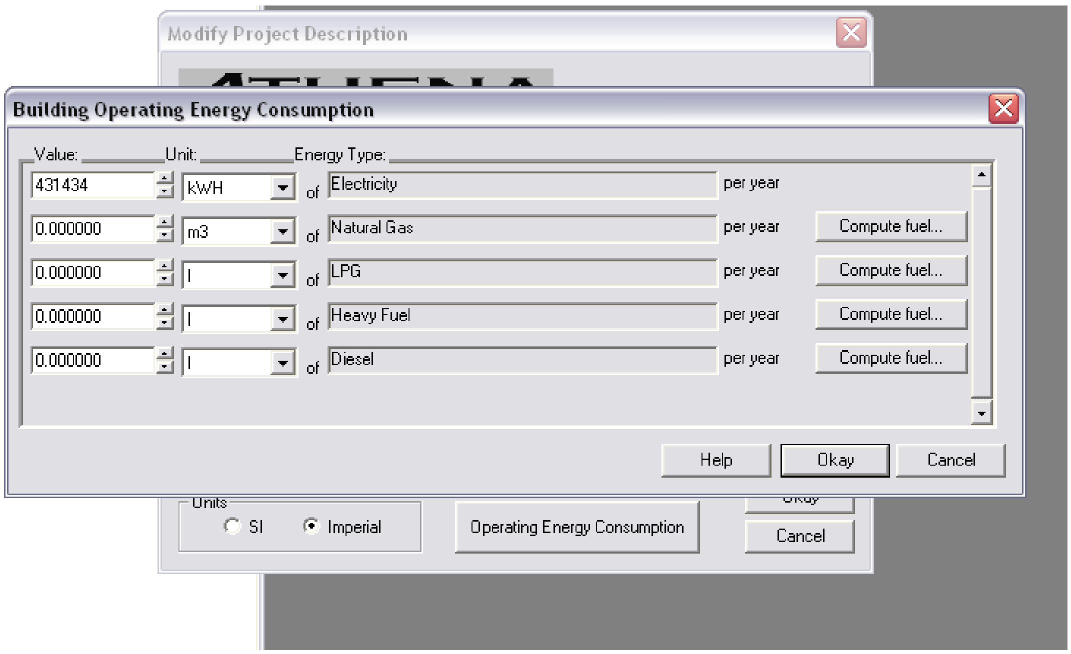


Figure 5.2-Energy Consumption Input (Athena Impact Estimator)

The energy consumption data was provided by the engineers at W.E. Monks & Co. who were responsible for the energy systems on the project. This building only consumes electricity and the actual consumption was provided for the first year and was used for the annual consumption. The consumption rates can be seen in Table 5.1. In the model, an average of the February and April 2008 energy consumption values were used for the month of March. The unusually high number reported in the table was due to system break in and calibration time and was not representative of what would be seen annually during the life of the structure. After clicking “Okay” on the Building Energy Consumption form, and the Project Description form, assemblies were added to the model by clicking “Add Assembly” and then the type of assembly on the toolbar.

Table 5.1- Monthly Energy Use in 4-H Building (2008-2009; in kWH units)

8-Jan	8-Feb	8-Mar	8-Apr	8-May	8-Jun	8-Jul
0	42,361	76,188	37,446	39,906	29,120	32,936
8-Jul	8-Aug	8-Sep	8-Oct	8-Nov	8-Dec	9-Jan
32,936	38,452	21,445	23,940	31,137	47,903	46,884

5.3.2 - Assemblies

The assemblies were added from the bottom up, or in the order of foundations, beams and columns, floors and roofs, and walls. For each category, the assemblies were added by floor starting with the basement. Assemblies were also broken up into regions depending on type specific properties of each assembly and named based on the location or number assigned on the construction documents.

5.3.2.1 - Foundations

The foundation plans were numbered according to numbered footing type and each of the numbered footings was copied from the original assembly created. A sample of the input for a footing can be seen in Figure 5.3.

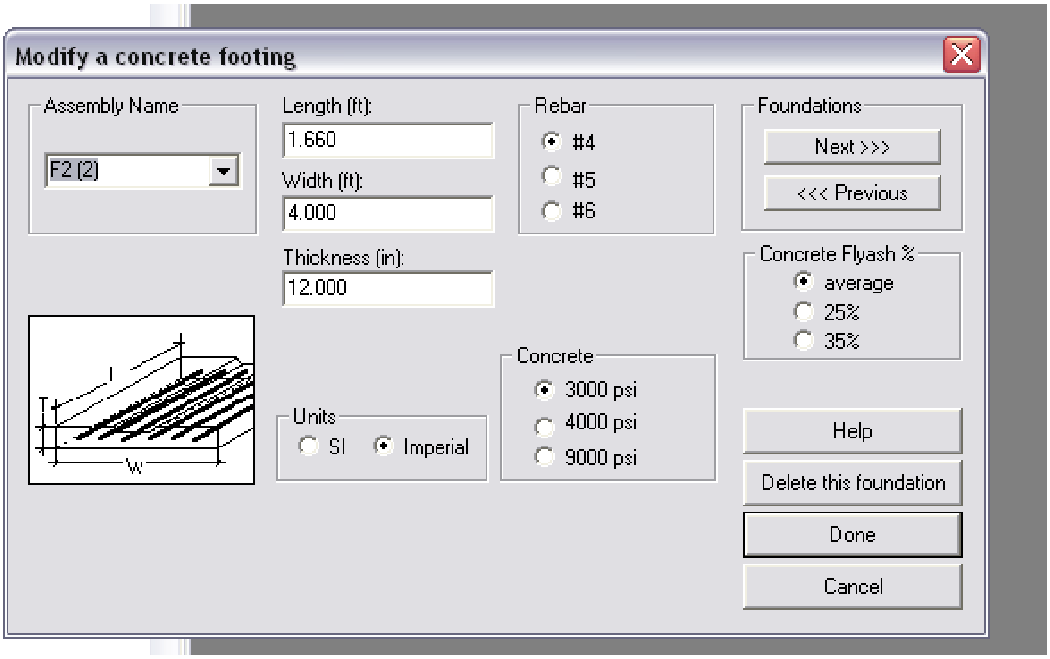


Figure 5.3-Concrete Footing Assembly (Athena Impact Estimator)

Not all of the features of the building are modeled entirely accurately because of limitations with the software such as rebar sizes and concrete strengths. Because of this the largest rebar size was used in cases where the specified bar size was larger than the available options. Similarly, the lack of a specified mix design in the construction documents for the concrete used led to the use of an "average" value for percent of cement replaced with flyash. However, it is unknown from the information available whether fly ash was used or not. The slab on grade for the basement floor was also added as part of the foundation assembly but the square footage and depth of the section was input instead of the other parameters as required in Figure 5.4. Again, in some areas the correct depth of the slab was not available so the closest available value was used.

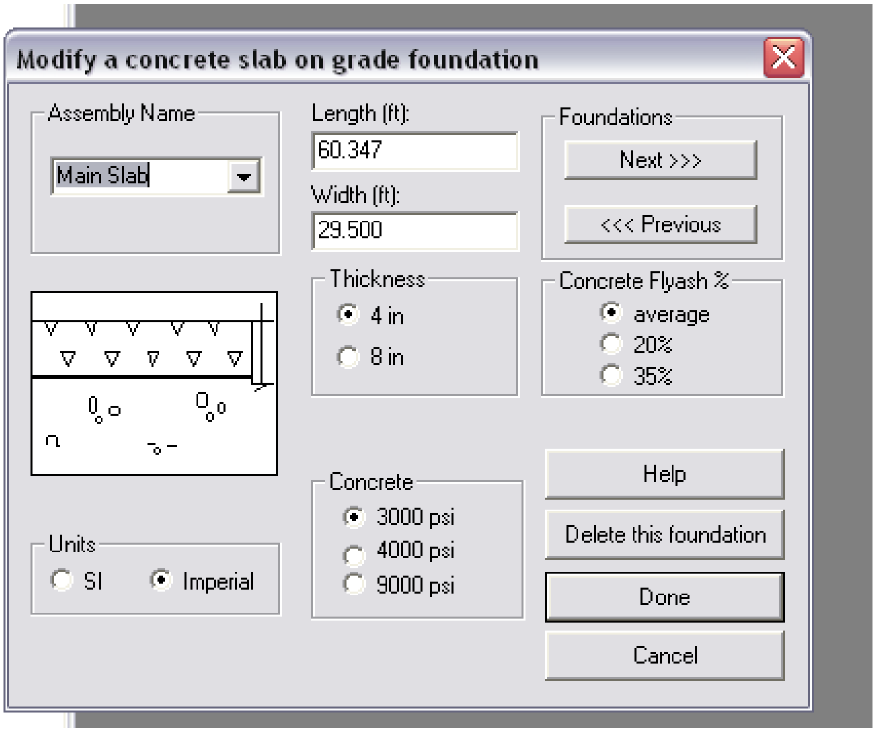


Figure 1.4-Slab on Grade (Athena Impact Estimator)

5.3.2.2 - Beams and Columns

After the footing and foundation assemblies were input into the program using the sizes and dimensions on the construction documents, the structural envelope was input into the model by adding "Beam and Column" assemblies. For this type of assembly the "Mixed Beam and Column" type was used because it would most accurately represent the actual structural envelope and because if the Wide Flange Beam and High Strength Steel option was used, then the span was larger than the actual value from the plans. A sample input can be seen in Figure 5.5. Each floor was divided into East and West regions due to the nature of the floor support for each section.

The structural beams and columns were input next, from the basement to the top floor. Each floor was divided into sections based on the size and configuration of bays.

The lowest values were used for the size of the bay and supported span because the actual spans were all less than what the options available.

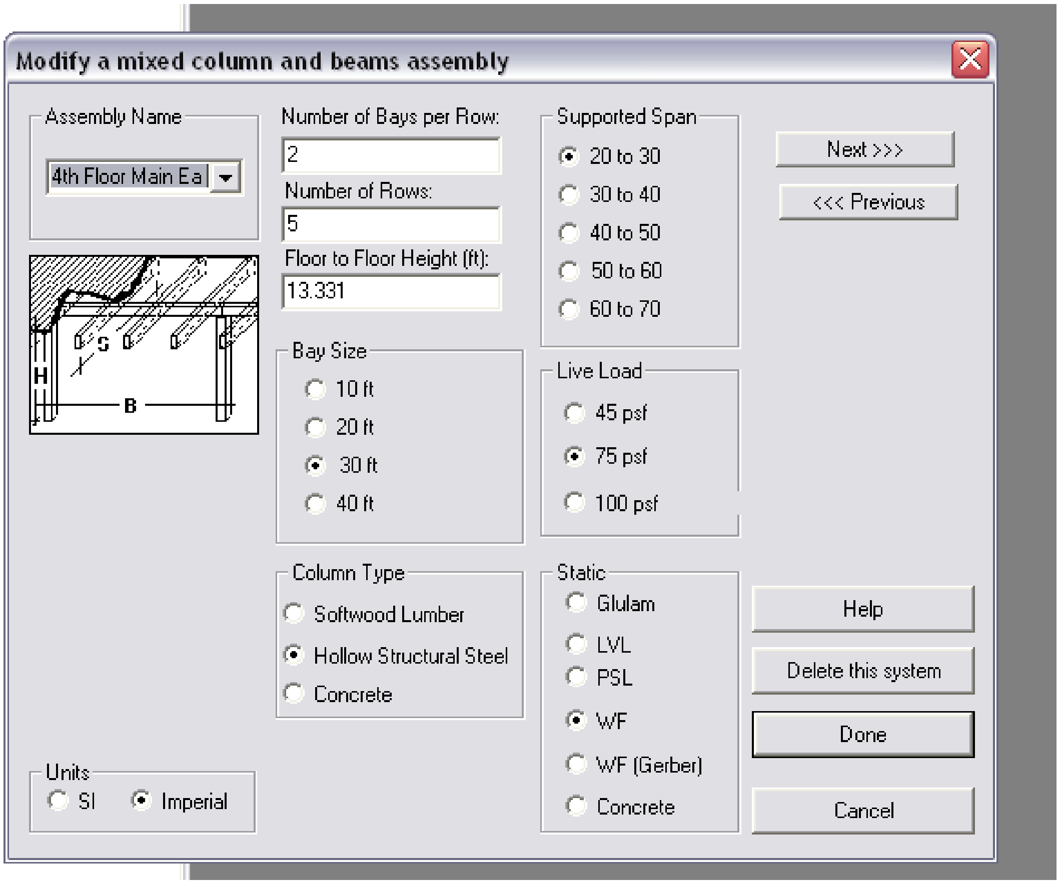


Figure 5.5-Column and Beam Assembly (Athena Impact Estimator)

As shown in Figure 5.5, the overall bay, row and floor height dimensions are chosen along with the span, load and type of beam and columns. For this application, steel columns and beams are used as well as the live load value specified in the construction documents for the occupational use for that area of the building (Morelli, 2006).

5.3.2.3 - Floors and Roofs

The next assembly that was added was for floors and roofs. The floors and roofs were divided by floor and region within the building. A sample of one of the floor assemblies can be seen in Figure 5.6.

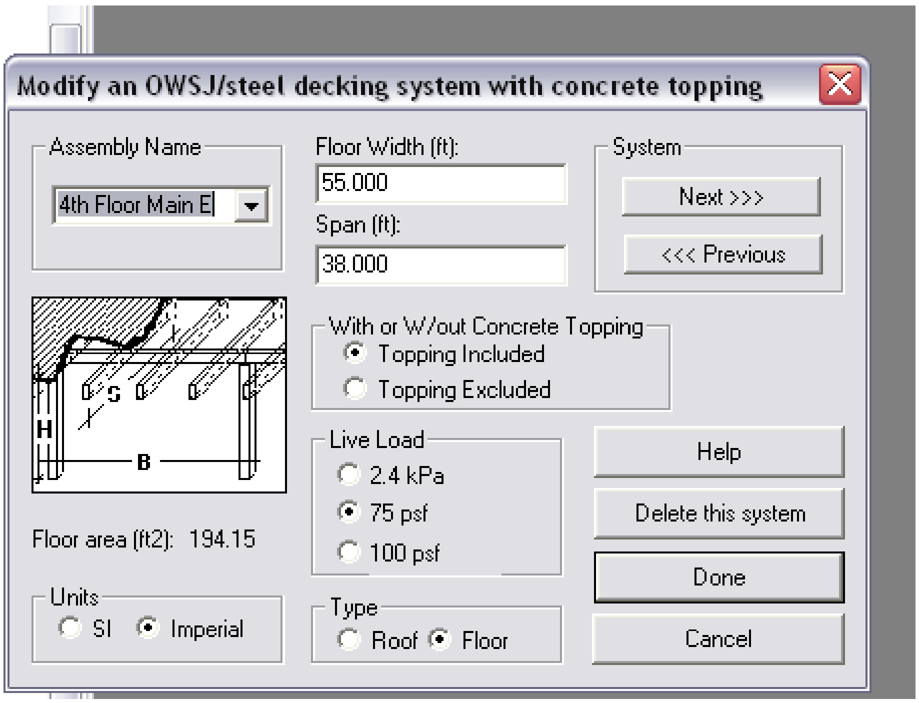


Figure 5.6-Floor Assembly (Athena Impact Estimator)

As can be seen from the figure, the floor assembly with "OWSJ/Steel decking system with concrete topping" was used as the flooring assembly for the 4-H Center building. The floor area was calculated from the construction documents and input into the program along with the live load for that area of the floor. This process was repeated for each floor.

5.3.2.4 - Walls

The wall assemblies are limited to two wall type definitions which is limiting as different wall sections are common. However, for this model, the walls will be modeled as either interior or exterior, and a representative of each type was created using the available materials and layers as found in the construction documents. Figure 5.7 shows the exterior wall layers as best represented by the available selection in the program. This selection can be made after an assembly is added by selecting “Edit→Define Envelope”.

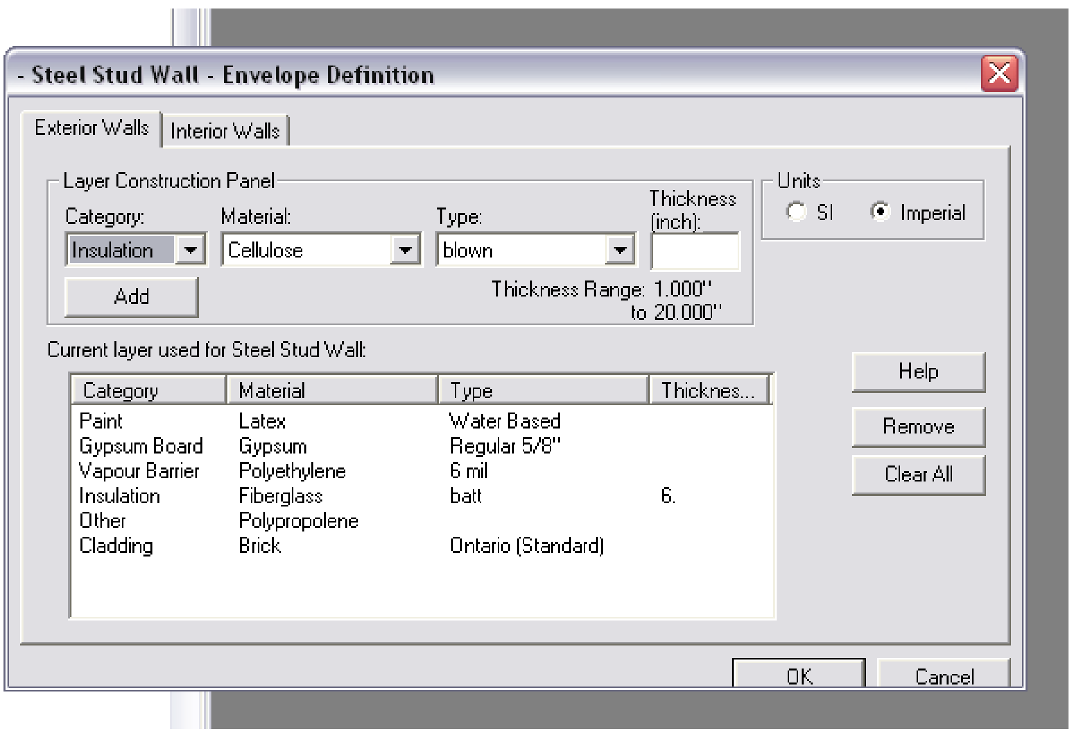


Figure 5.7-Wall Assembly Envelope (Athena Impact Estimator)

Figure 5.7 shows that different wall layers can be created using the selections available and each is added until the representative section is built up. After these envelopes are defined, the interior and exterior wall assemblies can be input as shown in Figure 5.8.

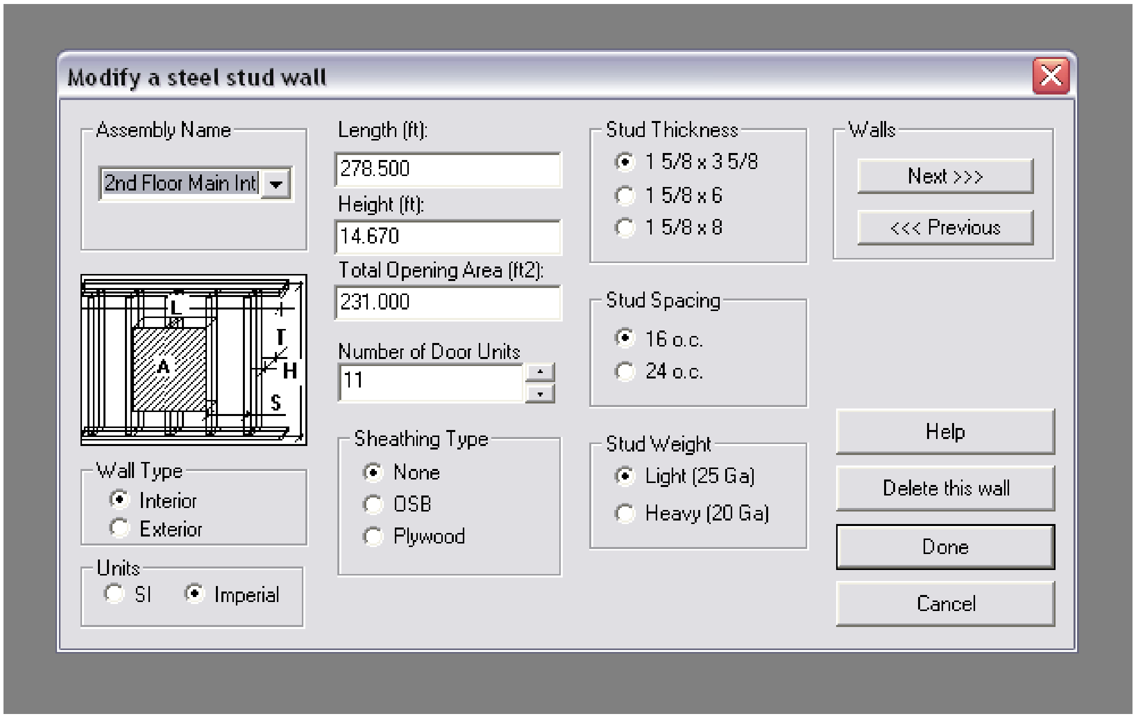


Figure 5.8-Wall Assembly (Athena Impact Estimator)

The input for the wall assemblies is based on the length and height of the wall. The openings such as windows and doors are included in the area of the total opening. Characteristics such as stud thickness, sheathing, stud weight, and stud spacing are also inputs. For this model, each wall was modeled separately by floor and direction. The size of each wall and openings were measured on the plans.

With the wall assemblies and the definitions of the envelopes, the model is complete and now results can be viewed using either a graphical or tabular format.

Chapter 6 – Results and Conclusions

6.1 – Program Output and Discussion

This section contains the output of the model of the 4-H Center using the Athena Impact Estimator. Table 6.1 contains the bill of materials generated from the program output.

Table B.1-Bill of Materials (Athena Impact Estimator)

Bill of Materials		
Material	Quantity	Unit
Concrete 20 MPa (flyash av)	421.81	yd^3
Concrete 30 MPa (flyash av)	209.60	yd^3
Mortar:	62.68	yd^3
Nails:	1.29	tons
Welded Wire Mesh / Ladder Wire	0.40	tons
Screws Nuts & Bolts	0.54	tons
Wide Flange Sections	14.43	tons
Open Web Joists	32.06	tons
Rebar, Rod, Light Sections	5.13	tons
Hollow Structural Steel	25.77	tons
Col Rolled Sheet	0.37	tons
Galvanized Decking	27.10	tons
Galvanized Studs	14.95	tons
Oriented Strand Board (3/8" basis)	24.75	msf
Batt. Fiberglass	109772.03	sf(1")
Ezpanded Polystyrene	26835.72	sf (1")
6 mil. Polyethelene	18798.85	sf
5/8" Regular Gypsum Board	61548.74	sf
Joint Compound	6.29	tons
Paper Tape	0.07	tons
Water Based Latex Paint	2783.24	gallons
Bricks	18.76	tons
EPDM Membrane	4655.86	lbs
Standard Glazing	28215.15	sf

These results show that the materials required for the wall envelopes are the majority of the materials required. A graphical representation in Figure 6.1 clearly shows that the resources required for the walls vastly outweigh every other assembly. This is because the walls complete the building envelope beyond the initial structural components. Similarly, if the walls were made solely of concrete, then the concrete required for the project would outweigh the other materials and resources for the project. In this project, the exterior walls were modeled as a layer of bricks, polyprpolene, 6 inch fiberglass insulation, a 6mil vapor barrier, 5/8 inch gypsum board and latex paint. The interior walls were modeled as latex paint followed by two layer of the gypsum board and another layer of paint. If, however, the building was modeled located in Atlanta, Georgia, the resource use by assembly group is very similar but slightly lower for some material types as can be seen in Figure 6.2. Note that only the embedded energy is applied to this graph.

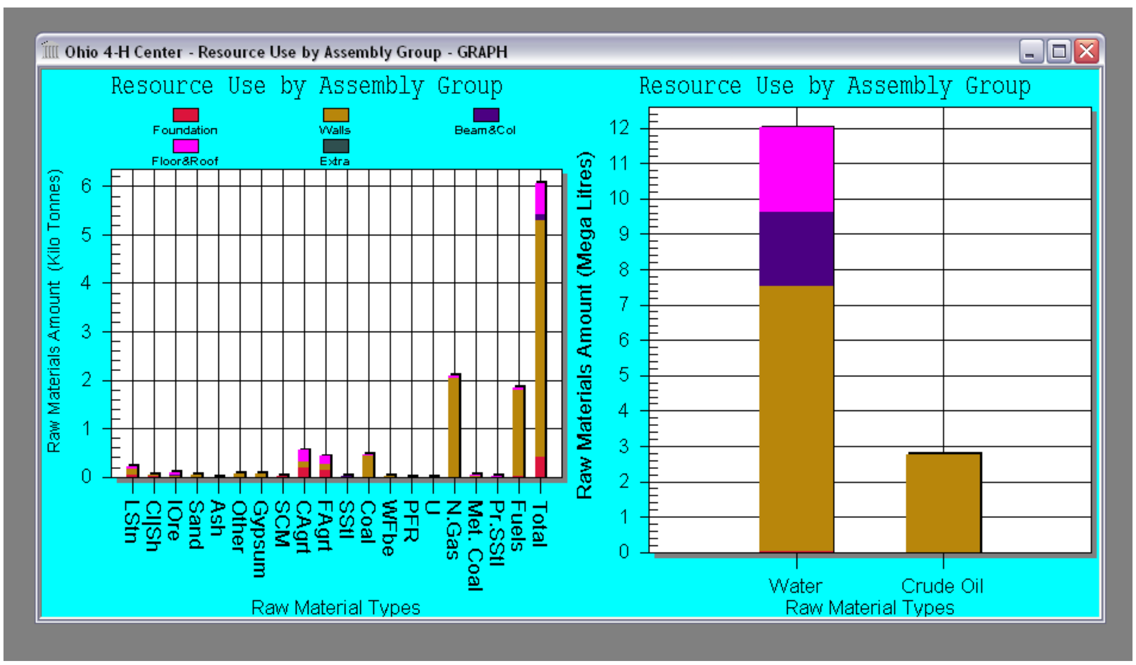


Figure 6.1-Resource Use by Assembly Group (Athena Impact Estimator)

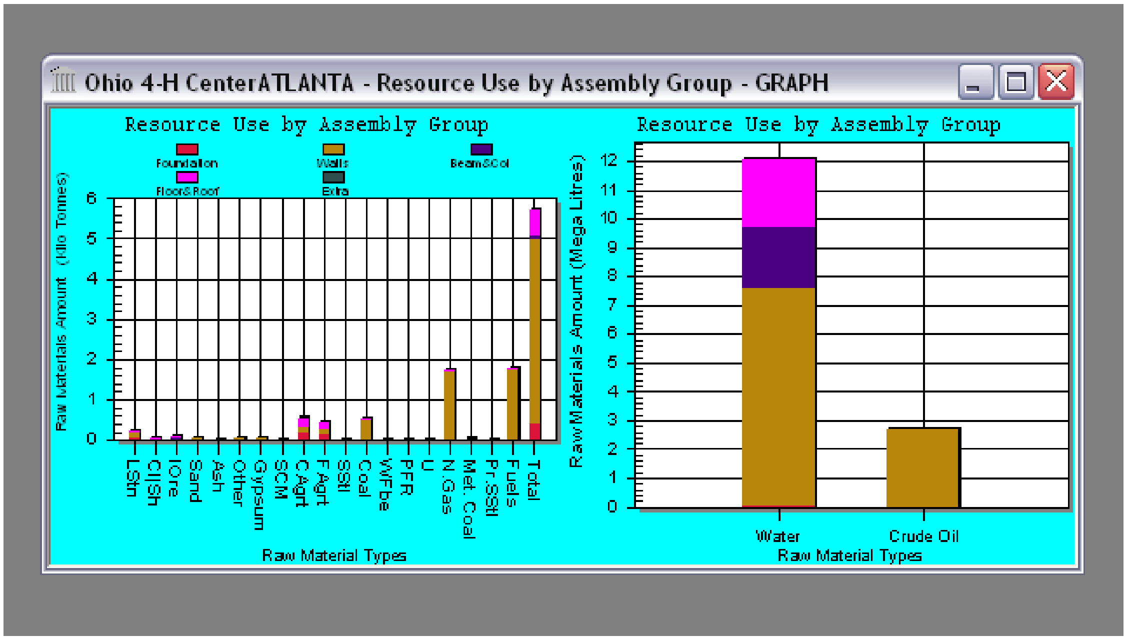


Figure 6.2-Resource Use by Assembly Group for Atlanta (Athena Impact Estimator)

It is important to note that the more resource consuming assembly is the walls. This makes sense because the walls make up the entire building envelope and interior walls consume more materials in addition. It is also interesting to note that the beams and columns have little effect on the environmental impact of the building. This indicates that whichever structural system is chosen, it will not have a large effect on the building if only beams and columns are used. However, additional factors may become important if concrete or str4uctural walls are used in the design.

Another important comparison that can be made from the model is the ratio of embodied energy of the structure with the operating energy or energy required to operate the building. As previously discussed, the embodied energy is the amount of energy put into the manufacture of materials, transportation, construction, repair and maintenance of the building. The operating energy is the energy that is used for the daily operation of the building. These can be compared by energy consumption and global warming potential as seen in Figure 6.3. The results show that the operating energy vastly outweighs the embodied energy of the structure which highlights the importance of designing and maintaining not only a well insulated, but energy efficient building. The Athena model demonstrates that 67.6% of the total energy goes to the operation of the building. Even with the efficient features of the 4-H Center, the operating energy still outweighs the embodied energy of the building.

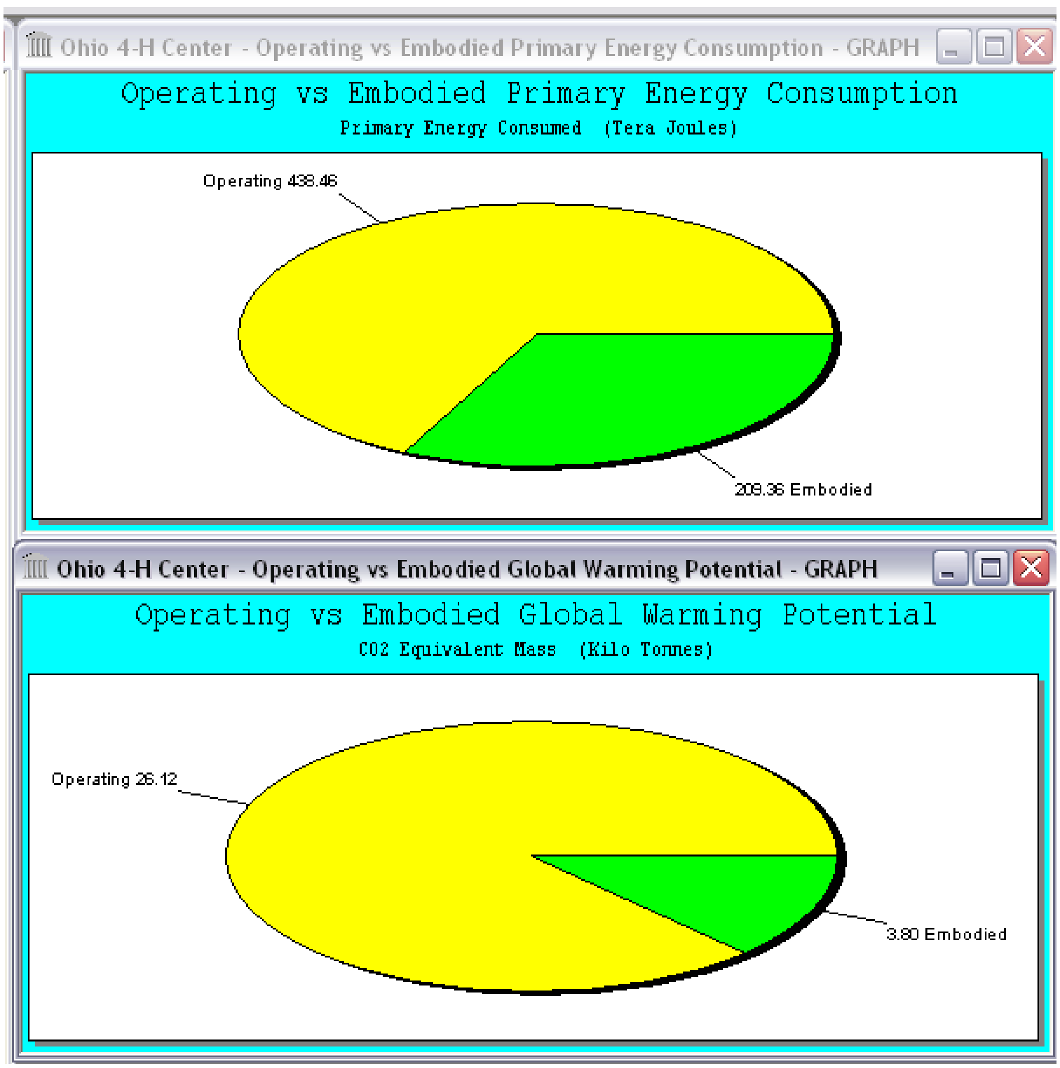


Figure 6.3- Operating Versus Embodied Energy (Athena Impact Estimator)

While it is interesting to note that the operating energy outweighs the embodied energy, the Athena software is also capable of comparing the energy consumption, resource use, and global warming potential associated within each life cycle stage to a total building life of 75 years. The graphs in Figure 6.4 indicate that the most consuming stage is manufacturing, which includes extraction of raw construction materials from the earth, their transport and manufacturing processes that turn them into their respective final product. This stage encompasses the manufacturing of the materials for each of the building assemblies, foundations, floors, beams and columns and walls. It can also be seen that the operation and maintenance (O & M), while consumes less energy, utilizes more resources over the lifetime of the structure. Note that the operating energy is compared on an annual basis. If it was the total operating energy for the building it would be about 75 times that value. Figure 6.5 shows the comparison abilities of the software. In this case, the 4-H Center is being compared with the same model that is located in Atlanta, Orlando in the Unites States and in Calgary, Canada instead of Pittsburgh. As can be seen, each location yields similar results. The demolition resources and energy are very similar, but the manufacturing, operating energy and construction values are quite different for reach location. So there is a definite impact on the assessment depending on the selected location of the model.

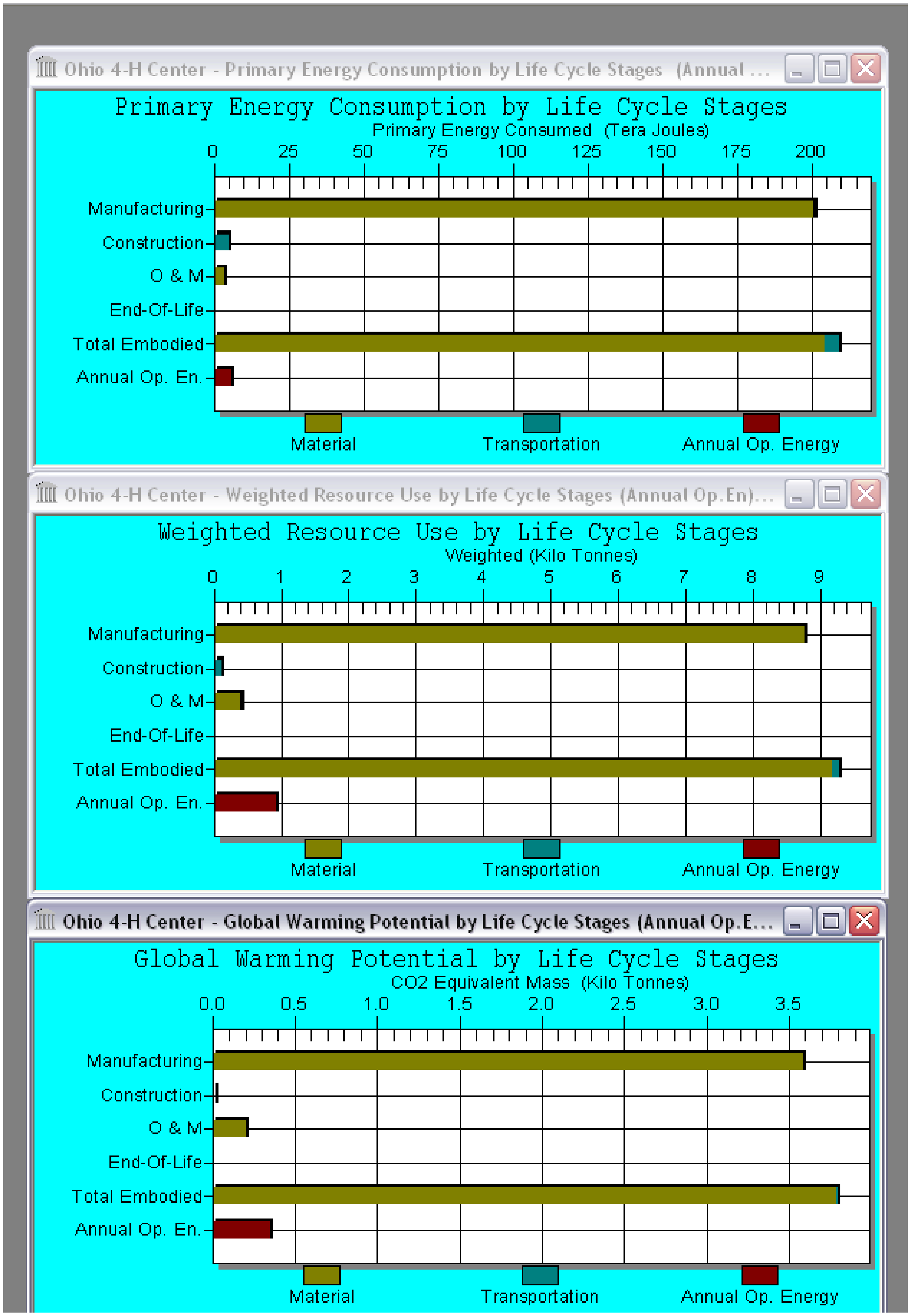
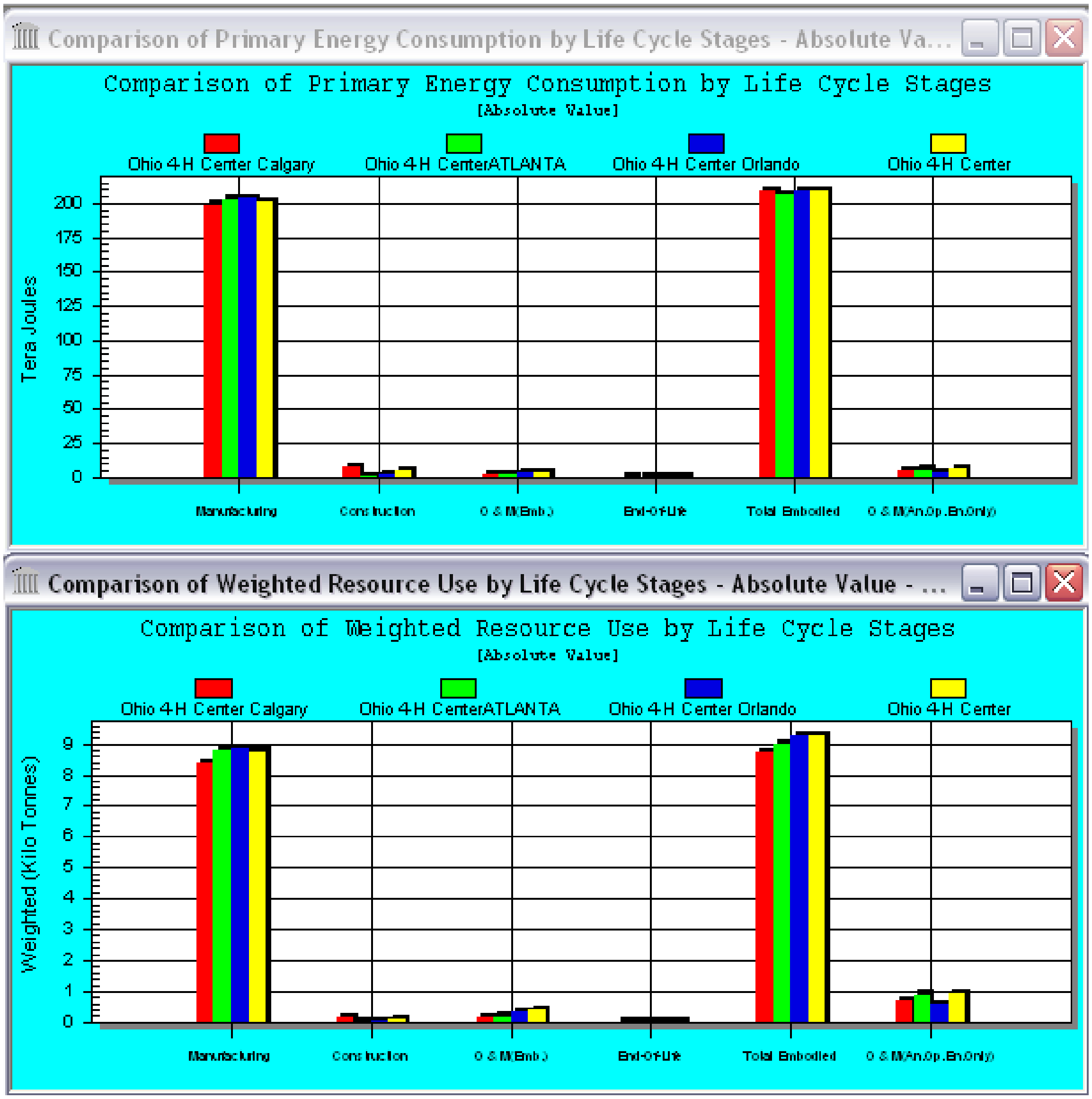


Figure 6.4-Energy Use and Resource Consumption by Life Cycle Stage (Athena Impact Estimator)



6.5-Atlanta Model Comparison (Athena Impact Estimator)

6.2 - Intended Use of Program

While presented here is one methodology for modeling a building with the Athena Impact Estimator, it is not exclusive. There may be other appropriate methods or software suitable for this type of analysis. While this method was able to produce a viable model of the features of the 4-H Center, it was difficult to produce the exact specifications of the building due to the limited input values of the program. With this in mind, it makes this program a better tool at an earlier point in the design stage, when comparisons between different design ideas are being addressed. Utilizing the program for this purpose would allow engineers and designers to quickly compare fairly representative structures, based on the major characteristics of the building assemblies without requiring too much detail, as details are not available to model. It is also important to note that this program does not consider the plumbing and water usage throughout the building's lifetime. Material maintenance and durability contribute as part of the repair and maintenance sub-routines which depend on the building type that is chosen.

6.3 - Review of Program Applicability

The current capabilities of the program are somewhat limited, depending on the location and other characteristics of the project. While this program is designed for projects in the U.S. and Canada, it still lacks the capability to handle projects in many areas of the country. Future versions should strive to incorporate more cities and regions into the programming. Even then, different contractors may obtain and transport similar construction materials from different locations for similar projects in the same city. The overall cost may be comparable, but the environmental impact can be significantly different. Athena or similar programs should provide more information about how their methodology or software is prepared or is based on. However, creating a perfectly accurate model of the exact routes and traffic patterns for transportation is outside of the scope of the software. The software uses data from the national Life Cycle Inventory to obtain the information for the various cities and materials and uses the bill of materials that is generated to apply the database information to the life cycle analysis (Athena Institute, 2008).

One of the limiting factors of the Athena software is how certain categories or assemblies are organized and defined. For instance, only two types of walls may be defined for the structure which is limiting to the designer and analysis. Furthermore, allowing more control over the default settings for the maintenance schedule could also enhance the reality of the simulation for the operation and maintenance of the building. Further constraining the model is the lack of options available, such as sizes, live load, and strength of materials. Therefore it is recommended the option for advanced modeling or changing of the default settings be implemented in future versions as well as additional inputs for wall types and the various assembly characteristics.

Chapter 7 – Summary and Conclusions

7.1 – Summary

Exactly how “green” or “sustainable” a certain building or material is compared to another is not easy to quantify. For several years now there has been an increase in interest for companies to use sustainable processes or to construct sustainable structures, yet there is still little information available about how to quantify various characteristics and features into a single and simple measure or indicator. This research demonstrated a way to model a LEED certified building on the campus of the Ohio State University using existing Life Cycle Analysis (LCA) software.

This research began with a review of the literature found in engineering journals such as Building and Environment as well as articles from gatherings of professionals and societies like the ASCE Structures Congress. These articles were reviewed for their applicability to this research were summarized in Chapter 2. Articles were sought based on two main subjects, the application of sustainable design to structural engineering and the use of a life cycle analysis to quantify the sustainable characteristics of building structures.

The third chapter presents a discussion of the application of sustainable design to structural engineering practice. This reviews the opportunities and criticisms of adopting sustainable practices by the existing industry. In addition, the ways that sustainable features are measured are discussed along with some of the available programs that are available for projects in North America; such as LEED, BEES, and Athena. The final topic is the features and concerns regarding the sustainability of timber, concrete and steel as a structural material.

In Chapter 4, a case study is performed on the Ohio 4-H Center regarding to the measures taken to meet the criteria for attaining LEED certification. Each criterion that was met by either the design or construction teams was detailed as a case study for a campus building to achieve LEED certification.

The main research of this project is presented as a methodology in Chapter 5 and the results of the LCA in Chapter 6. The model of the Ohio 4-H Center was created using the Athena Impact Estimator. This model was created by creating separate assemblies, for the foundations, floors, beams and columns, and walls to create the entire building envelope. The operating energy consumed for the first year was also input as a representative annual operating energy for the building. The results were then displayed as graphical representations, although a tabular form may be used, to compare the resource and energy consumption of the life cycle stages, including manufacture, transportation, construction, operation and maintenance and demolition.

7.2 – Conclusions

The conclusions of the research are presented at the end of each chapter and some are summarized here.

- Structural engineers already engage in sustainable design at a basic level by conserving material to find the least weight solutions.
- There are limited opportunities for structural engineers to engage in sustainable design due to the nature and requirements of the discipline.

- Design integration of different disciplines early in the conceptual stage is the key to developing sustainable facilities.
- Out of the three structural materials (timber, concrete and steel), timber possesses the least embodied energy from manufacturing and can be grown unlike concrete aggregate and steel alloys.
- Structural designers can reduce material and energy consumption through Optimization of each Life Cycle stage.
- The LEED criteria that can be met through structural design decisions are limited to the use of recycled materials such as steel and concrete or the specification of materials found locally.
- LEED criteria are basic indicators and do not provide an accurate comparison of different designs because the sustainable value of each point is not weighted on an equal basis.
- Software such as the Athena Impact Estimator can be used in the conceptual or early design process to compare the resource and energy consumption of several different designs.
- Results from the Athena model show that the wall assemblies consume the most energy and resources while the structural envelope consumes very little in comparison.
- Results also indicate the manufacturing life cycle stage is responsible for most of the embodied energy of the building and the construction phase, as modeled, primarily only consumes resources through transportation.
- The Athena Impact Estimator is limited in use for a wholly designed building given detailed plans and documents because of restrictions on many of the program inputs.

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APPENDIX A: LCA Tool Matrix (RMIT)

APPENDIX 1

Building LCA and associated tool matrix

Summary of attributes

Athena Model tools classification	USER TYPE	BLCA categories	TOOLS	Relevance to Aust.	to B & C	LCA covers materials	use	disposal	Impact categories used Green house	Energy	Air	Ozone depl.	Toxicity	Water pollution	Volume water	Solid waste	IAQ	Database Present	edit DB	LCC
LEVEL 1 - product comparison tools	Material and building product R&D	1. Detailed LCA modelling tools - material product level																		
			Boustead (UK)	medium	low	yes	yes	yes	yes	yes	yes	yes	yes	yes	?	yes	no	yes		no
			GaBi (GER)	low	low	yes	yes	yes	yes	yes	yes	yes	yes	yes	?	yes	no	yes		no
			KCL-ECO (FIN)	low	low	yes	yes	yes	yes	yes	yes	yes	yes	yes	?	yes	no	yes		no
			LCAiT (SE)	low	low	yes	yes	yes	yes	yes	yes	yes	yes	yes	?	yes	no	yes		no
			PEMS (UK)	low	low	yes	yes	yes	yes	yes	yes	yes	yes	yes	?	yes	no	yes		no
			SimaPro (NL)	medium	low	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	no	yes	yes	possible
			TEAM (Fra)	low	low	yes	yes	yes	yes	yes	yes	yes	yes	yes	?	yes	no	yes		no
LEVEL 2 - whole building design decision or decision support tools	Designer, env professionals	1. Detailed LCA modelling tools - Building Component level																		
			Assessed tool Japan	low	high	yes	yes	yes	yes	yes	no	no	no	no	no	no	no	yes	?	no
			BRI- LCA (Jap)																	
			Athena (Can)	low	high	yes	yes?	yes	yes	yes	yes	no	yes	yes	no	yes	no	yes		no?
			BEE 1.0 (FIN)	low	high	yes	no	yes	yes	no	yes	yes	yes	yes	?	yes	no	yes	?	no
			ECO methods (Fra)	low	high	yes	yes	no	yes	yes	yes	no	yes	no	?	?	yes	Yes		Yes
			EcoQuantum (NL)	low	high	yes	yes	yes	yes	yes	yes	yes	yes	yes	?	yes	no	yes		no
			LISA (Aus)	high	high	yes	yes	yes	yes	yes	yes	no	no	no	yes	no	no	yes	no	no
			Optimize (CAN)	low	high	yes	yes	yes	yes	yes	yes	yes	yes	yes	?	yes	yes	yes	?	yes
			SIA D0123 (CH)	low	high	yes	no	no	yes	yes	yes	yes	yes	yes	yes	yes	no	yes?	?	no
	Designer, env professionals	2. LCA Design tools																		
			EcoScan (NL)	low	low	Yes	yes	yes	yes	yes	yes	yes	yes	yes	no	yes	no	yes	yes	no
			Envest (UK)	low	high	yes	yes	yes	yes	yes	yes	yes	yes	yes	no	yes	no?	yes		no?
			ECOit (NL)	low	low	yes	yes	yes	yes	yes	yes	yes	yes	yes	no	yes	no	yes	no	no
			LCAit	low	low	yes	yes	yes	yes	yes	yes	yes	yes	yes	no	yes	no	yes limited	no ?	no
	Designer, env professionals	3. LCA CAD tools																		
			BEES (USA)	low	high	yes	yes	yes	yes	yes	yes	yes	yes	yes	?	yes	no?	yes		yes

Figure A.1-Building LCA Tool Matrix Page 1 (RMIT)

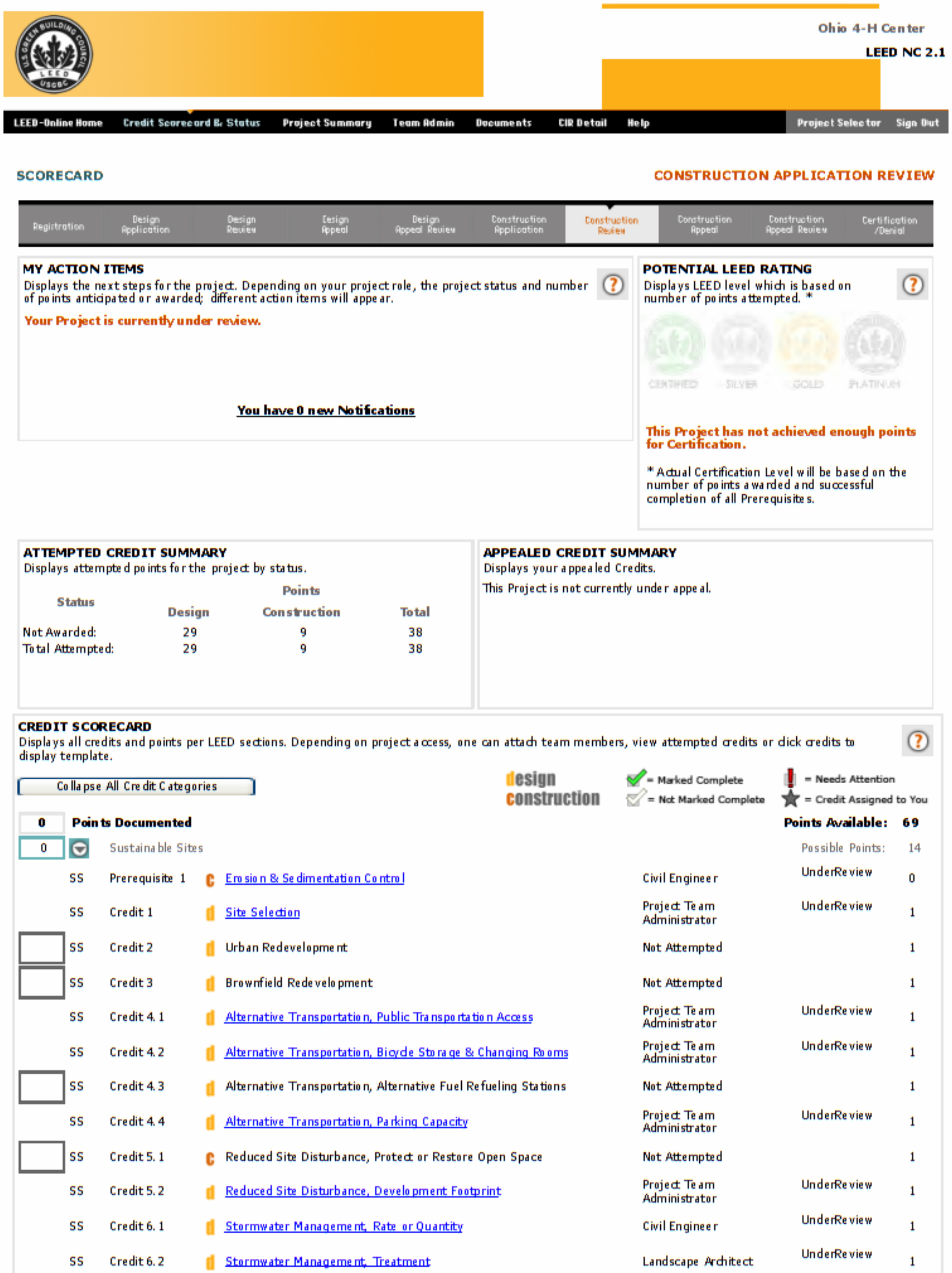
			Building design advisor	low	high	yes	yes	yes	yes	yes	yes	yes	yes	yes	?	yes	yes	yes		no
			Ecopro (GER)	low	high	yes	no	no	yes	yes	yes	yes	yes	yes	?	yes	no	yes	?	no
			Ecotect (Aus)	high	high	yes	yes	yes	yes	yes	no	no	no	no	?	no	yes	Yes		Yes
			Energy 10 (USA)	low	high	energy	energy	no	yes	yes	no	no	no	no	?	no	no	yes	yes	no
			ENER-RATE (Aus)	high	high	energy	energy	no?	yes	yes	no	no	no	no	?	no	no	yes?		yes
			EPCMB (UK)	low	high	yes	yes	yes	yes	yes	yes	yes	yes	yes	?	yes	no	yes	?	no
			Environmental Profiles of Construction Materials, Components and Buildings																	
			EQUER (Fra)	low	high	yes	yes	yes	yes	yes	yes	yes	yes	yes	?	?	no	yes		no
			Green Building Advisor (USA)	low	high	yes	yes	yes	no	yes	no	no	no	no	?	no	yes	yes but hidden		no
			LCAid (Aus)	high	high	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	?	yes		no
			Legoe (GER)	low	high	yes	yes	yes	yes	yes	yes	yes	yes	yes	?	yes	yes	yes	?	yes
			OGIP (CH)	low	high	yes	yes	yes	no	yes	no	no	no	no	yes	yes	no	yes	?	yes
			PAPOOSE (F)	low	high	yes	yes	yes	yes	yes	yes	yes	yes	yes	?	yes	yes	yes	?	no
			SBI (DK)	low	low	yes	yes	yes	yes	yes	yes	yes	yes	yes	no	yes	no	yes	?	no
			TEAM (Fra)	low	high	yes	yes	yes	yes	yes	yes	yes	yes	yes	?	yes	no	yes		no
	Designer, env professionals	4. Green product guides and Checklists																		
			BEPAC (UK)	low	high	no	no	no	yes	yes	yes	yes	?	?	?	?	no	yes		no
			EPM - check list (NL)	low	high	yes	yes	yes	yes	yes	yes	yes	yes	yes	?		no	yes		no
			ECDG (Jap)	low	high	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	no	no	no
			Green housing A-Z (Jap)	low	high	n/a	n/a	n/a	n/a	n/a	yes	n/a	yes	n/a	n/a	n/a	n/a	no	no	no
			EcoSpecifier (Aus)	high	high	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	yes	no	no
Level 3 - Whole building assessment framework or systems	Regulators, designers, env professionals	5. Building Assessment Schemes	tools and rating																	
			BUNYIP (Aus)	high	high	no	energy	no	no	yes	no	no	no	no		no	no	no?		no
			DOE 2.2 (US)	low	high	no	energy	no	no	yes	no	no	no	no		no	no	no?		no
			Beaver/ESPII	low?	high	no	energy	no	no	yes	no	no	no	no		no	no	no?		no
			BREGains (UK)	low	high	no	energy	no	no	yes	no	no	no	no		no	no	no?		no
			Ökoprofile (NOR)	low	high	yes	yes	no	yes	yes	yes	no	no	no	yes	yes	yes	yes?	?	no
			BREEAM (UK)	low	high	no	no	no	yes	yes	yes	yes	yes	no	?	?	yes	?		no

Figure A.2-Building LCA Tool Matrix Page 2 (RMIT)

		GBTool (international)	medium	high	yes	yes	yes	yes	?	?	?	?	?	?	?	?	?	?	?
		NatHERS (Aus)	high	high	no	energy	no	no	0-5 score	no	no	no	no		no	n0	no?		no
		SEDA (Aus)	high	high	no	energy	no	yes	yes	no	no	no	no		no	no	no?		no
		E2000 (CH)	low	high	yes	yes	yes	no	yes	no	no	no	no	yes	yes	no	yes?	?	no
		LEED (USA)	low	high	yes	yes	yes	yes	?	?	yes	?	?	?	?	yes	?		?
		Energy certification for buildings (FIN)	low	high	no	yes	no	yes	yes	no	no	no	no	no	no	no	yes?	?	no
Env. Professionals and Tool developers eg LCAid and CSIRO	Embodied energy - Input/output tools																		
		Carnegie Melon I/O model (USA)	low	low	yes	energy	yes	yes	yes	yes	yes	yes	yes	yes	yes	no	yes	no	yes
		NIRM (Jap)	low	low	yes	energy	yes	yes	yes	yes	yes	yes	yes	yes	yes	no	yes	no	yes

Figure A.3-Building LCA Tool Matrix Page 3 (RMIT)

APPENDIX B: LEED Online Scorecard



Ohio 4-H Center

LEED NC 2.1

LEED-Online Home | Credit Scorecard & Status | Project Summary | Team Admin | Documents | CIR Detail | Help | Project Selector | Sign Out

SCORECARD

CONSTRUCTION APPLICATION REVIEW

Registration | Design Application | Design Review | Design Appeal | Design Appeal Review | Construction Application | Construction Review | Construction Appeal | Construction Appeal Review | Certification /Denial

MY ACTION ITEMS

Displays the next steps for the project. Depending on your project role, the project status and number of points anticipated or awarded; different action items will appear.

Your Project is currently under review.

You have 0 new Notifications

POTENTIAL LEED RATING

Displays LEED level which is based on number of points attempted. *

CERTIFIED SILVER GOLD PLATINUM

This Project has not achieved enough points for Certification.

* Actual Certification Level will be based on the number of points awarded and successful completion of all Prerequisites.

ATTEMPTED CREDIT SUMMARY

Displays attempted points for the project by status.

Status	Design	Construction	Total
Not Awarded:	29	9	38
Total Attempted:	29	9	38

APPEALED CREDIT SUMMARY

Displays your appealed Credits.

This Project is not currently under appeal.

CREDIT SCORECARD

Displays all credits and points per LEED sections. Depending on project access, one can attach team members, view attempted credits or click credits to display template.

Collapse All Credit Categories

design construction

= Marked Complete = Not Marked Complete = Needs Attention = Credit Assigned to You

0 **Points Documented** **Points Available: 69**

0 Sustainable Sites Possible Points: 14

SS	Prerequisite 1	Erosion & Sedimentation Control	Civil Engineer	UnderReview	0
SS	Credit 1	Site Selection	Project Team Administrator	UnderReview	1
SS	Credit 2	Urban Redevelopment	Not Attempted		1
SS	Credit 3	Brownfield Redevelopment	Not Attempted		1
SS	Credit 4.1	Alternative Transportation, Public Transportation Access	Project Team Administrator	UnderReview	1
SS	Credit 4.2	Alternative Transportation, Bicycle Storage & Changing Rooms	Project Team Administrator	UnderReview	1
SS	Credit 4.3	Alternative Transportation, Alternative Fuel Refueling Stations	Not Attempted		1
SS	Credit 4.4	Alternative Transportation, Parking Capacity	Project Team Administrator	UnderReview	1
SS	Credit 5.1	Reduced Site Disturbance, Protect or Restore Open Space	Not Attempted		1
SS	Credit 5.2	Reduced Site Disturbance, Development Footprint	Project Team Administrator	UnderReview	1
SS	Credit 6.1	Stormwater Management, Rate or Quantity	Civil Engineer	UnderReview	1
SS	Credit 6.2	Stormwater Management, Treatment	Landscape Architect	UnderReview	1

Figure B.1-LEED Online Scorecard (Page 1)

	SS	Credit 6.2	Stormwater Management, Treatment	Landscape Architect	UnderReview	1
	SS	Credit 7.1	Landscape & Exterior Design to Reduce Heat Islands, Non-Roof	Not Attempted		1
	SS	Credit 7.2	Landscape & Exterior Design to Reduce Heat Islands, Roof	Project Team Administrator	UnderReview	1
	SS	Credit 8	Light Pollution Reduction	HVAC Engineer	UnderReview	1
0		Water Efficiency			Possible Points:	5
	WE	Credit 1.1	Water Efficient Landscaping, reduce by 50%	Landscape Architect	UnderReview	1
	WE	Credit 1.2	Water Efficient Landscaping, No Potable Use or No Irrigation	Landscape Architect	UnderReview	1
	WE	Credit 2	Innovative Wastewater Technologies	Not Attempted		1
	WE	Credit 3.1-3.2	Water Use Reduction	HVAC Engineer	UnderReview	2
0		Energy & Atmosphere			Possible Points:	17
	EA	Prerequisite 1	Fundamental Building Systems Commissioning	HVAC Engineer	UnderReview	0
	EA	Prerequisite 2	Minimum Energy Performance	HVAC Engineer	UnderReview	0
	EA	Prerequisite 3	CFC Reduction in HVAC&R Equipment	HVAC Engineer	UnderReview	0
	EA	Credit 1.1-1.10	Optimize Energy Performance	HVAC Engineer	UnderReview	10
	EA	Credit 2.1-2.3	Renewable Energy	Not Attempted		3
	EA	Credit 3	Additional Commissioning	Not Attempted		1
	EA	Credit 4	Ozone Depletion	Not Attempted		1
	EA	Credit 5	Measurement & Verification	Not Attempted		1
	EA	Credit 6	Green Power	Not Attempted		1
0		Materials & Resources			Possible Points:	13
	MR	Prerequisite 1	Storage & Collection of Recyclables	Project Team Administrator	UnderReview	0
	MR	Credit 1.1-1.3	Building Reuse	Not Attempted		3
	MR	Credit 2.1-2.2	Construction Waste Management	Project Team Administrator	UnderReview	2
	MR	Credit 3.1-3.2	Resource Reuse	Not Attempted		2
	MR	Credit 4.1-4.2	Recycled Content	Project Team Administrator	UnderReview	2
	MR	Credit 5.1-5.2	Local/Regional Materials	Project Team Administrator	UnderReview	2
	MR	Credit 6	Rapidly Renewable Materials	Not Attempted		1
	MR	Credit 7	Certified Wood	Not Attempted		1
0		Indoor Environmental Quality			Possible Points:	15
	EQ	Prerequisite 1	Minimum IAQ Performance	HVAC Engineer	UnderReview	0
	EQ	Prerequisite 2	Environmental Tobacco Smoke (ETS) Control	Project Team Administrator	UnderReview	0
	EQ	Credit 1	Carbon Dioxide (CO2) Monitoring	HVAC Engineer	UnderReview	1
	EQ	Credit 2	Increase Ventilation Effectiveness	HVAC Engineer	UnderReview	1
	EQ	Credit 3.1	Construction IAQ Management Plan, During Construction	Not Attempted		1
	EQ	Credit 3.2	Construction IAQ Management Plan, Before Occupancy	Not Attempted		1
	EQ	Credit 4.1-4.4	Low-Emitting Materials	Project Team Administrator	UnderReview	4
	EQ	Credit 5	Indoor Chemical & Pollutant Source Control	HVAC Engineer	UnderReview	1
	EQ	Credit 6.1-6.2	Controllability of Systems	Not Attempted		2

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	EQ	Credit 6.1-6.2	Controllability of Systems	Not Attempted		2
	EQ	Credit 7.1	Thermal Comfort, Comply with ASHRAE 55-1992	HVAC Engineer	UnderReview	1
	EQ	Credit 7.2	Thermal Comfort, Permanent Monitoring System	HVAC Engineer	UnderReview	1
	EQ	Credit 8.1	Daylight & Views, Daylight 75% of Spaces	Project Team Administrator	UnderReview	1
	EQ	Credit 8.2	Daylight & Views, Views for 90% of Spaces	Project Team Administrator	UnderReview	1
0		Innovation & Design Process			Possible Points:	5
	ID	Credit 1	Innovation in Design 1.1	Project Team Administrator	UnderReview	1
	ID	Credit 1	Innovation in Design 1.2	Project Team Administrator	UnderReview	1
	ID	Credit 1	Innovation in Design 1.3	Project Team Administrator	UnderReview	1
	ID	Credit 1	Innovation in Design 1.4	Project Team Administrator	UnderReview	1
	ID	Credit 2	LEED Accredited Professional	Project Team Administrator	UnderReview	1

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Figure B.3-LEED Online Scorecard (Page 3)